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Observations and measurements of containerized black spruce seedlings growing in a greenhouse

A. Gonzalez and A.L. D'Aoust

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Laurentian Forestry Centre
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Cover Photo: View of the main building (Laurentian Forestry Centre) and the new greenhouses.

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RÉSUMÉ

Malgré des variations importantes au niveau des conditions climatiques quotidiennes dans la serre, aucun effet significatif n'a été noté dans les paramètres morphologiques des semis d'épinette noire récoltés. La différence la plus importante que l'on ait noté provient des extrêmes de température rencontrés périodiquement. La somme des degrés-jours de croissance, comme démontré par de nombreuses observations, est reliée à la qualité des semis produits. Les différentes modalités d'arrosage et de fertilisation n'ont pas eu d'effets notables sur la morphologie ou la composition chimique des semis. L'utilisation successive du 20-20-20 et du 10-52-10 totalisant 260 mg de fertilisant par cellule a donné des résultats satisfaisants. Néanmoins, le practicien dispose d'une marge de manoeuvre qui se situe autour de ce chiffre.

Chaque année, 25 000 semis d'épinette noire ont été cultivés en conteneurs, durant trois années consécutives, dans une serre vitrée. Deux saisons de cultures, le printemps et l'été, ont été mises à l'essai avec seize semaines de développement en serre et trois en ombrière. Des données d'ordre climatique, nutritionnel et morphologique

ABSTRACT

Although daily climatic conditions varied significantly in the greenhouse, they had little effect on the morphological parameters of black spruce seedlings. One of the most significant differences recorded was some periodic extreme temperatures. The quality of the seedlings produced was frequently related to the sum of growing degree-days for a particular season. Different watering and fertilizing regimes did not show any significant effect on the morphology nor the chemical composition of the seedlings. Successive use of 20-20-20 and 10-52-10 fertilizers, for a total of 260 mg/cell, gave satisfactory results. Nevertheless, the practitioner can work at ease around this figure.

Each year, during three consecutive years, 25 000 containerized black spruce seedlings were grown in a greenhouse. Seedlings were kept in a greenhouse for sixteen weeks and under a shadehouse for three weeks for two growing periods. Climatic factors were recorded and samples were collected periodically for morphological and nutritional evaluation

ainsi que d'autres ayant trait au substrat et à la composition chimique foliaire et racinaire ont été périodiquement analysées.

using substrate analysis throughout the growing periods.

FOREWORD

Under the provincial reforestation program, the Laurentian Forestry Centre (LFC) has contributed to research efforts through its studies on some of the basic aspects of greenhouse production of containerized seedlings.

Theoretically, growing seedlings on a peat substrate is relatively easy; it is a method that anyone can employ. However, in the context of a reforestation program covering the entire province of Quebec, the problem takes on a whole new dimension. When producing hundreds of millions of seedlings, care must be taken to minimize errors at each stage of the reforestation process.

It is in this spirit of working towards a better understanding of certain aspects of the overall problem that a team of four researchers from the LFC studied several specific points: greenhouse production, the physiology of hardening off, development of the root system, and tree planting and monitoring.

INTRODUCTION

Greenhouse production of containerized seedlings is not a recent technique. Since the late 1960s, Ontario and British Columbia have been cultivating many thousands of containerized seedlings under greenhouse conditions (Armson and Sadreika 1979; Mathews 1971). A great deal of research has been aimed at developing this technology (Waldron 1972; Tinus et al. 1974, Scarratt et al. 1982). In Quebec, where this application is more recent, two workshops have been held on the topic (1980, 1984).[a]

Where the commercial producer is concerned, however, it is unlikely that, for a given particular type of production, the optimum conditions will exist for all factors studied by the researcher. In this report, we have tried to cover a variety of the growing conditions generally encountered by the producer and, if possible, to identify potential difficulties. It is not our objective to repeat the work of Tinus and MacDonald (1979) or Langlois and Carrier (1984), but rather to try to make new inroads in order to arrive at a better understanding of greenhouse production of containerized black spruce seedlings.

MATERIAL AND METHODS

The biological material for these different production periods was always obtained from the same provenance of black spruce (*Picea mariana* Mill. B.S.P.), from Roberval, Danville County.[b]

Seedling production and most observations were carried out in a small (45 m²) experimental glass greenhouse (B_4) at the Laurentian Forestry Centre (LFC). Steam heating was provided by tubular radiators running around the inside of the greenhouse at ground level

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a Sponsored by the Canadian Forestry Service, the ministère de l'Énergie et des Ressources and l'Ordre des ingénieurs forestiers du Québec, Premier (1980) et Deuxième (1984) atelier de travail sur la culture des semis en récipients. Sainte-Foy, Québec.

b Kindly provided by the Regeneration Division, Quebec Department of Energy and Resources.

Ventilation was provided by a fan (3/4 HP), where air entered at the top and was distributed through a long perforated polyethylene cylinder. Lighting was provided by 150-watt incandescent bulbs (one bulb for each 2.2 m² of cultivated surface) to ensure a long photoperiod.

In some cases, for purposes of comparison, we also used two other smaller greenhouse sections (A_6 and A_7), each of which had its own built-in cooling system (Artic Air Cooler). Because of their position and the partial obstruction of the top of the greenhouse, these two sections received different amounts of sunlight.

Finally, to ensure a 16-hour photoperiod, two different lighting systems were installed in these two sections. The smaller section (A_6) was equipped with Gro-lux fluorescent tubes (Sylvania: F96T12GRO), while in the larger section (A_7) two high-intensity lamps were used one high pressure sodium lamp (Sylvania-Lumalux 400 watts) and one improved mercury lamp (Sylvania-Metalarc 400 watts); the height of these two lamps was adjusted to provide equivalent lighting at the level of the plants.

The project consisted of two crops per year: spring (February to June) and summer (May to September), each involving about 13 000 seedlings, most of which were black spruce. All seedlings were intended for research, either for measurement and analysis during the production period, or for field observations.

Our observations fall into 5 categories:

a) Climatic data: temperature, relative humidity, radiant energy;
b) Nutritional data: watering, fertilization;
c) Substrate data: water content, soluble salts, pH;
d) Morphological data: height, dry weight, diameter, etc.;
e) Chemical, foliar, and root analysis data: nitrogen, phosphorus, potassium.

The greenhouse production extended over a 16-week period, followed by a period of 3 to 4 weeks in a shadehouse before planting. We used two main types of containers: the CRIQ extrusion tube (1981, 1982) and the Rigipot IPL-45 (1983). The Styrofoam, Can-Am and

Paperpot were also used, but for another purpose.

The substrate used was sphagnum peat moss from Pointe-au-Père, sieved at 10 mm. The East Angus provincial nursery provided us with the necessary trays, which were filled mechanically on-site. A preliminary study was carried out (Gonzalez 1981) on some of the chemical and physicochemical properties of the sphagnum peat moss.

RESULTS AND DISCUSSION

Climatic data

Temperature

Temperature was recorded daily using a thermograph. Average temperature was calculated from readings taken at set times: every 6 hours starting at midnight. The charts of daily maximum and minimum temperatures in the greenhouse show significant heat fluctuation (Figures 1a, 1b, and 1c). This phenomenon was particularly evident during the summer production period, with temperatures sometimes reaching alarming highs (40-44°C) despite the ventilation system.

Thus, from our experience over the project's three-year duration, it would seem that use of a greenhouse, whether glass or polyethylene, in the summer may create more problems than it offers advantages. Indeed, the frequency histogram of heat conditions for each summer period indicate a degree of overheating which could even prove harmful to black spruce production, although no serious problems were detected in terms of survival or growth. We feel that any temperature above 40°C may be harmful to a large proportion of the seedlings. In summer 1982, there were about 30 instances of temperatures above 40°C (Figure d).

Relative humidity

In a greenhouse such as the one we used, it is practically impossible to control relative humidity. Repeated waterings, with a traveling watering boom, and the air drawn in from outside have a perceptible effect on the water content of the ambient air. We simply recorded this parameter in order to observe the seasonal fluctuations which, as shown in the graphs, are considerable for the daily maximum and minimum values (Figure 2a, 2b, and 2c).

What we were most interested in observing, however, was the behavior of temperature in relation to relative humidity variables inside a greenhouse compared to a closed system. In a closed system, water content and temperature are directly proportional. In a greenhouse, things are quite different.

We observed that maximum daily temperatures in the greenhouse are always followed by minimum relative humidity values; these two variables are closely correlated (Figure 2d), for both summer and spring productions.

Examination of the opposite phenomenon, i.e., the interaction between minimum temperatures and the corresponding maximum relative humidity values, showed no correlation. This is only an apparent contradiction, given that maximum humidity inevitably occurs at the set watering times and that these times do not coincide with those at which the lowest daily temperatures were recorded.

To delve into this aspect in greater detail, we used time values recorded by means of a micrologger in spring 1984. We found significant correlations with these "synchronized" values, although the direction of proportionality differed in each case (Figure 2e).

There is a practical corollary to these observations: a correction is to be made in the relative humidity of the greenhouse by "misting" at times of high temperature, to avoid creating humidity conditions unfavorable (10-20%) to seedlings and/or planning watering times so as to coincide with the period of intense heat, between 11:30 and 14:30 according to our readings.

Factors related to heat and energy

Here, we will briefly explain a few factors closely linked to plant growth; control of these factors may prove useful for greenhouse management.

Total growing degree-days: This is a commonly used unit which, given its cumulative nature, illustrates heat tone in a greenhouse over a given period. It is calculated as follows:

$$DD = \sum (\bar{x} - 5)$$

where $\bar{x}$ = average daily temperature (Villeneuve 1971).

Table 1 shows the values obtained for the years studied.

Table 1. Growing degree-days corresponding to different production periods (calculated over 100 days)

	1981	1982	1983
Spring	1917	2178	1898
Summer	2030	2119	1973

Our production periods were spread over about 3 months (91 to 105 days). We therefore based our calculations on a period of 100 days to make comparisons consistent.

Radiant energy: Three aspects were considered when we studied seedlings' exposure to the sun: photoperiod duration, radiant energy, i.e., the calorific value of the sunshine, and the number of photons that can be used for photosynthesis (400 to 700 nm, measured in micromoles · m^{-2} · sec^{-1}.

We took advantage of the months offering the maximum photoperiod. Seeding for the spring production was always carried out around February 10, and the summer growing period always ended in late August. However, to ensure a minimum photoperiod, we used artificial lighting (16 h/day) from 150-watt incandescent bulbs equipped with shades. each bulb lighting 2.2 m^2 of the cultivated surface.

At set times, daily measurements were taken of the radiant energy in the greenhouse using a light meter (Type 190S produced by Li-Cor Inc., Lincoln, Nebraska, USA). Given their nature, the values obtained contained only very punctual information difficult to use in establishing a daily or seasonal energy profile.

To establish an energy profile representative of a production, continuous recording instruments capable of providing an integrated daily value must be used. Two light meters (Li-Cor, Model LI-190S) were used to measure the radiant energy; they were placed on each of the tables, level with the growing surface, and protected from water by suitable glass covers.

On very bright summer days, we placed black plastic netting on the greenhouse roof to protect the seedlings. This inevitably reduced the values recorded.

As an example, we compiled the data obtained using a Campbell CR 21 micrologger, for the 1984 growing periods (Figure 3). The growing degree-days in the form of a monthly average slightly masked daily heat fluctuations recorded in late March during the installation of the ventilation system. Similarly, and since all our measurements were taken inside the greenhouse, the maximum radiant energy recorded in June (268 hours of insolation) was not accompanied by maximum temperature, essentialy owing to the watering and ventilation combination used to prevent overheating.

Nutritional data

Watering

In order to adequately control the water content of the substrate, we felt it essential to be familiar with the features of our watering system. We focused on three points: yield, uniformity, and fertilizer dilution. A detailed description of these three aspects was presented at a workshop on the production of containerized seedlings (Gonzalez 1984).

Although only an easily produced series of calibrations is involved, we feel they might provide very valid information to any producer wanting to manage his production. Other aspects of watering will be discussed in the section on fertilization.

Fertilization

The fertilization regime for these three years remained essentially unchanged, except for a few modifications related to application sequences. The choice of fertilizers, 20-20-20 and 10-52-10, was based on the existing literature (D'Aoust 1980; Van Eerden 1974; Tinus and MacDonald 1979; Timmis 1974). Reports generally seemed to agree that replacing the first 15 weeks' nitrogen-rich regime with another whose dominant element is phosphorus at the end of the production period increases seedling hardiness and, consequently, survival in the field.

The apparatus used consists of a diluter (10.0 L) filled with a concentrated fertilizer solution and attached to the water line, producing suction and thereby injecting fertilizer into the watering system. A series of preliminary calibrations enabled us to adjust the device to our needs, considering the area to be watered (22 m^2) and the traveling watering boom flow rate (27 or 48 L per complete cycle according to the sprinkler used and the adjustment of the diluting container). Table 2 shows the result of a calibration.

Using these basic data and knowing the number of daily cycles, we were able to draw a profile of the watering and fertilization program used for each production period (Figure 4a, 4b, and 4c). The number of waterings was based on the desired water content. The *modus operandi* was discovered gradually and empirically. Nevertheless, having reliable basic data on the yield of the traveling watering boom and the diluter, it was relatively easy to develop a satisfactory working rhythm.

Table. 2. Experimental watering conditions related to watering and fertilization (Example: spring 1981 production)

Initial concentration in the diluter (10 L):
500 g 20-20-20[1] +28.3 g $MgSO_4$ $7H_2O$ = 52.83 g/L (17 250 µmhos cm^{-1})
Concentration after dilution: 0.8 g/L (555 µmhos cm^{-1})[2]
Volume used in 1 complete watering cycle: 27 L
Number of cycles with fertilization: 124 (20-20-20) and 132 (10-52-10): 256 cycles
Fertilizer added: 27 x 256 x 0.8 = 5 530 g
Fertilizer used on the seedlings[3]: 75% of 5 530 = 4 147 g
Fertilizer added/1 cavity: 4 147 ÷ 13 000 = 319 mg
Number of seedlings: 13 000 - 13 500
Number of cycles with one diluter load: 25[4]

[1] The values obtained for 10-52-10 are essentially the same.

[2] Average value of 10 measurements

[3] We estimate that 75 to 80 percent of the fertilizer fell onto the cavities.

[4] This value depends on the adjustment of the diluter. The concentration of the fertilizer applied decreases slowly with the number of cycles.

As shown in figures 4a, 4b and 4c, we tested a number of fertilizer application methods, combining qualitative and quantitative aspects. In spring 1981, we applied a fertilizer daily (0.8 g/L), wich was incorporated into each watering. We allowed a 9-day period between two fertilizer applications. In other cases, we chose a series of 1, 2, or 3 consecutive days of fertilization, followed by periods of 3-7 days of watering. The amounts of fertilizer varied from 200 to 300 mg/cavity.[c]

In terms of morphology and chemical composition of leaves, roots, and substrate, analysis of the results never showed any significant differences

[c] Approximatively 250 mg of fertilizer, on average 14 percent nitrogen or 35.3 mg N total, for an average water content of 70 percent in the substrate; this is equivalent to a hydroponic solution of 630 ppm N.

related to watering and fertilization conditions. This confirms the viewpoint of many physiologists (Callot et al., 1982), who hold that plants generally exercise selective self-control in regard to available nutrients for maintaining the mineral balance of their tissues. This balance can only be upset when there is an excess or a deficiency of nutrients.

Thus, the practitioner enjoys leeway given the numerous possible combinations of commercially available fertilizers, and dosage, while respecting limits of a reasonable order of magnitude. (D'Aoust and Gonzalez[d]).

Finally, for large-scale production, fertilizer should be applied through an injector attached to the watering system.

Substrate data

Throughout the project's three years, we used 116 mL extrusion tubes from the CRIQ, made of Cellukraft paper and lined with a thin layer of polyethylene (Barbulescu 1981). They were supplied to us, ready for seeding, by the East Angus provincial nursery. The substrate always consisted of peatmoss, extracted at Pointe-au-Père, sieved at 10 mm. A study on the main physical and chemical characteristics of this substrate was published by Gonzalez (1981) from which we have selected three aspects for the present study; controlling them could prove extremely useful in accelerated greenhouse production. These aspects are: water content of the substrate, soluble salt level, and pH level.

Water content

The importance of the watering regime in plant production has long been acknowledged and clearly plays a very significant role in this project. We therefore attempted to measure the water content periodically in an attempt to control it by adjusting it to the needs of the seedlings.

A certain amount of information exists on this topic (Tinus and MacDonald 1979; Carlson 1980; Langlois and Carrier 1984), but empiric observations were our guide in determining the amount of water needed by the plants, given seasonal variations, plant age, etc.

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[d] Publication in preparation

Project carried out in growth chambers (Gonzalez 1981; D'Aoust and Gonzalez[d]) have also pointed out certain aspects related to the watering regime of substrates, in terms of the speed of desiccation, distribution of water in the container, maintenance of fixed levels of water content, etc.

The use of the Bouyoucos device (for measuring electrical resistance of a block of gypsum inserted in the earth), very widespread in agronomy, is inapplicable on peat substrates, whose water content has to be very high for proper development of the seedlings. The measurement of the soil's water content, using a manual Time-domain reflectrometry, is not yet available for a substrate or sphagnum peatmoss (Topp 1984 personal communication). We therefore opted for a gravimetric method involving the periodic weighing of a certain number of trays distributed diagonally across the tables. The results were expressed as a quantity of water retained and saturation ratio. A series of preliminary checks enabled us to adjust the number of waterings to obtain the desired water level content for each production period.

The results obtained (Figures 5a, 5b and 5c) vary slightly from one year to the next, yet maintain a certain similarity. All show an initial period of 4-6 weeks in which a level of 80-85 percent is maintained; this level is gradually reduced to 70 percent for the rest of the production period. Fluctuations in the water content of the sphagnum peatmoss used as the substrate increase as the production period advances, i.e., as foliar interception intensifies. Lack of uniformity, in watering or in the filling of containers, may explain these relatively significant fluctuations for certain production periods (spring 1981).

The watering regime described above produced good results in terms of seedling growth and, generally, in terms of their root system and outer appearance. Nevertheless, more specific studies, conducted in growth chambers (D'Aoust and Gonzalez[d]), showed that it is possible to obtain good, if not better, results by working with water contents 20 percent lower than those used during the three years referred to in this study.

Soluble salts

The possibility of soluble salts accumulating in the substrate must be prevented to avoid problems of toxicity. In addition to periodic monitoring, the method we used has the advantage of allowing remedial measures to be applied

Table 3. Conductivity in μmhos · cm^{-1} of water-saturated extracts from a container[1]. Final volume: 1 L

	Contact time		
	1 hour	3 hours	24 hours
De-ionized water	17	20	19
Tap water	110	110	112

[1] Initial conductivity: de-ionized water: 0.75 μmhos · cm^{-1}
tap water: 150 μmhos · cm^{-1}

immediately should such accumulation occur. In such cases, seedlings must be watered abundantly given the peat's ability to retain metallic cations. Prior research (Gonzalez 1981) showed that 200 to 300 mL of water per container were necessary to substantially reduce salinity of the percolate when the substrate was highly fertilized.

A conductimetric analysis of an extract taken from the saturated peat (Lukas and Rieke 1972) has proven to be a rapid, reliable technique for evaluating soluble salts present in a substrate. This technique provides an overall evaluation using fertilizer curves in ppm and conductivity in μmhos. The two fertilizers used, the 20-20-20 and 10-52-10 (Plant Prod Co. Ltd., Ontario), produce virtually the same curves for the concentration range generally used in our seedling production. A series of preliminary tests with unfertilized peat enabled us to establish the conductivity of an extract taken from a container.

A look at the figures in Table 3 shows that the peat already retains some of the ions (probably Ca^{+2}) from tap water, since the average conductivity of the extract (110 μmhos) is lower than that of the original water (150 μmhos). Moreover, since there is a linear relationship between conductivity and concentration, the salinity of a container extract using deionized water can be calculated as follows:

$$\mu mhos = 0.374\ ppm + 2.96$$

In other words, 20 µmhos equals 45.5 mg/L of soluble salts.

We took these values, as well as the salinity contributed by tap water, into account in the cumulative calculations used to plot the following curves (Figures 6a, 6b and 6c). In the interests of clarity in the analysis and interpretation of salinity curves, it is important to consider the manner in which results are expressed. By analogy with the hydroponic cultivation of plants we have used the volume of water present within a container as the support medium within which the ions act as nutrients. It is this volume that concentrations, expressed in ppm, refer to.

The curve values may be changed into percentages of soluble salts compared to dry weight in a container (9 g) using the formula:

$$\% \text{ soluble salts} = R \times \% \text{ W.C.} \times 89 \cdot 10^{-7}$$

where:

R = reading in ppm of the curve,

W.C. = percentage of substrate's water content (average value for the month under study).

A sequence of graphs allows us to monitor the changes in the substrate's soluble salt level. Each curve illustrates a different aspect of the same process. The upper curve shows the gradual accumulation of soluble salts calculated using daily supplies from watering, fertilizer injections, and also the peat's initial salinity.

The calibration curve showing "concentration vs. conductivity" allowed us to calculate total quantities of salts retained by the substrate which, in theory, accumulate, since there are no losses through leaching. This provides an overall profile of soluble salt levels and also an idea of the order of magnitude at any given time in the production period.

The lower curve was obtained using experimental values from the conductimetric analysis of saturated extracts taken from 8 containers chosen along a diagonal across tables at 4-5 day intervals. Considerable fluctuations may be observed in the group of containers measured the same day; these fluctuations tend to become more pronounced towards the end of the production period. The salinity as expressed by this curve also includes the three sources of salt cited above.

Essentially, a study of these curves shows the ability of sphagnum peat moss to retain mineral elements, of which (60 percent) originated from the fertilizer.

In terms of plant nutrition, this means that the peat substrate offers a comfortable safety margin for the prevention of posible toxicity due to excess fertilizer. The substrate's retention capacity is shown graphically by the difference between the slopes of the two curves.

The main goal of these measurements and calculations of the soluble salts in the substrate was to produce a semi-quantitative approach designed to increase our understanding of fertilization mechanisms as far as the experimental conditons of a greenhouse allow us to do so.

A more detailed study would have necessitated allowing for the foliar mass' interception of the fertilizer once the seedlings reach a height of 10-12 cm; this may explain the fluctuations observed towards the end of the production period. It would also have been necessary to take into account the quantities of mineral salts absorbed by the seedlings (approximately 20-25 mg/15-week old seedling).

Fertilizer and substrate pH

We also periodically monitored changes in the pH level, both in the water and fertilizer used on seedlings and in the substrate (Table 4).

The method used was very simple and required only a minimum of equipment: a standard pH meter equipped with an appropriate electrode.

A weekly sample appears sufficient to ensure acceptable control, although if inequalities are suspected in the water used in the greenhouse, closer monitoring is required. A series of 8 trays placed diagonally across the tables provided the necessary cavities for the weekly substrate measurements (1 g of peat in 15 mL of distilled water). Fertilizer samples were taken at fixed points in the greenhouse on the days when the nutrient solution was applied.

Variations in the pH of the watering and fertilizer solution were in the 3 to 10 percent range, in terms of the variation coefficient, and were probably due to variations in the pH of the water used in the greenhouse.

The pH values for the substrate showed a slight decrease, about one pH

unit occurring progressively throughout the production period (Figures 7a, 7b, and 7c). This acidification process is understandable given the salt accumulation due to watering and fertilization, which slowly free a certain number of H^+ ions from the peat; the pH meter detects their presence after 15-20 weeks of growth. The average values observed, however, are perfectly acceptable for good growth in black spruce seedlings. The observable differences, from year to year or season to season, can probably be traced to the different lots of peat which we were supplied.

Table 4. Average pH values of watering and fertilizer solutions and substrates[1]

	1981		1982		1983	
	Spr	Sum	Spr	Sum	Spr	Sum
Water and fertilizer	7.33	6.46	6.78	7.12	6.71	7.11
Substrate	4.94	4.98	5.6	5.94	5.83	4.56

[1] Spr = Spring; Sum = Summer

Morphological data

Morphological data should reflect the environmental conditions for the different production periods. As indicated previously, the total growing degree-days varied little for the different periods because greenhouse facilities provides some control. Therefore one could expect a degree of uniformity in the material grown (Table 5) which is the case (0.24 g of total dry weight with a variation coefficient of 27 percent). For these same production periods, accumulation of dry weight in roots is also a function of the cumulative ambient temperature (Figure 8), but no relationship of this nature has been observed in the shoots.

Periodic readings of radiant energy under greenhouse are insufficient to explain the full importance of this

growth factor. For example, for two productions periods (Figure 9) which produced similar results (0.76 and 0.72 g of dry weight), photon flux data taken at mid-day do not provide a basis for predicting the accumulation of dry weight. On the other hand, if we take the periodic photon flux data for the three enclosures and establish the accumulation of relative radiation, that is, compared to the highest cumulative photon flux measured during the first four production periods, we obtain three curves for seedling growth vs. relative radiant energy in our three enclosures (Figure 10a).

From another viewpoint, after twenty weeks' growth, the total dry weight and relative radiant energy shows a significant correlation (Figure 10b; corr. coeff. = 0.67).

This last observation leads us to believe that, in general, photon flux was a limiting factor in smaller sections (A_6, A_7) as compared to the greenhouse area (B_4) and, carbon dioxide concentration was not.

Table 5. Morphological dimensions of black spruce seedlings after 15 weeks of greenhouse production[1]

Period	Height[1] (cm)	Diameter[1] (mm)	Total dry weight (g)
1	10.7	1.3	0.32
2	12.7	1.3	0.25
3	10.7	1.4	0.33
4	10.5	1.1	0.19
5	8.9	1.3	0.16
6	11.5	1.3	0.25
7	8.6	1.3	0.17
8	9.0	1.2	0.23

[1] The minimum and maximum numbers of seedlings used to obtain these measurements were 16 and 50 respectively.

If readings are taken more regularly, that is recorded contineously, a logarithmic growth curve is observed as a function of the cumulative radiant energy (Figure 11).

Basic data may be processed to show more clearly the effect of climatic conditions on growth. For example, the mean relative growth rate can be used to calculate the accumulation of dry weight compared to a stable value, over relatively short periods (Figure 12). One observes a reduction in the MRGR with increasing the weekly mean photon flux measured. It would appear that the growth rate was modified by the temperature in the greenhouse, which was relatively high for this species (D'Aoust 1978; Pollard and Logan 1975).

Although we will not elaborate on the hardening off treatment, which is another field of research, it is interesting to mention the beneficial effect observed on seedlings that were placed in a shadehouse. Seedlings in shadehouse grew 2 to 30 percent more in height and dry weight than seedlings that had remained in the greenhouse (D'Aoust and Trudel 1984). It seems also that excessive heat during summer 1982, would explain poor growth during this period. In short, as stated above, the degree of heat present in the greenhouse on several occasions would appear to be excessive for black spruce seedlings under cultivation.

In another context, a study of the mass ratio shows that it changes constantly during seedling growth (Figure 13). This type of observation was already reported by Langlois and Carrier (1984). As can be seen clearly from the graphic presentation of the ratio, however, identification of a desirable ratio for seedlings is indicative of little, unless the maximum and minimum values of one the factors involved is stated.

Chemical composition of foliage and substrate

The mineral composition of plant tissues has long been viewed as an indispensable complement of soil analysis. Commonly used in plant physiology and pedology studies, this technique can supply very valuable data for determining fertilizer requirements, confirming visual symptoms of mineral deficiencies or establishing nutrient levels.

Much literature is available on the topic, particularly in the field of agriculture. In forestry, some recognized reference works on nutrition include: White (1948), Swan (1960), and Armson and Sadreika (1979) and on nutrient

deficiency diagnosis: Wilde (1958), Lafond (1958), Wehrmann (1959), and Tamm (1954).

We systematically monitored changes in the main elements, N, P, and K (total) in the sections above ground and in the roots of seedling from the fifth week on. Concurrently, we measured the proportions of these elements (Total N and available P and K) in the peat substrate. Data from these analyses may be used for various purpose, both theoretical and applied. For example, it would be possible to compare assimilation rates for two production periods; monitor changes in mineral composition by seedling age; or, over the longer term, relate foliar composition to plantation site fertility.

Seedling warping problems in the greenhouse could also be better understood with the help of foliar analysis. Similarly, in-depth study of foliar composition in greenhouse-grown seedlings and wild seedlings might discover an explanation for the attraction of freshly planted seedlings for certain animals (hares, deer), which cause considerable damage to reforestation sites.

Results obtained appear in the form of graphs (concentration in ppm as a function of growth time), although they are not always easy to interpret. Attempts to produce a specific profile of quantities of elements added and those absorbed by the seedlings or found in the substrate encounter an entire range of experimental variations arising from the very nature of experimental conditions. These variations, which are difficult to control and measure, include: a) lack of uniformity in watering, leading to variations of 10 to 15 percent in quantities recorded at different places on tables (Gonzalez 1984); b) variations in flow rates through watering equipment, related to pressure changes in the water supply line; c) losses between seedling containers or interception by foliage; d) fluctuations of approximately 10 percent in the dry weight of the substrate between containers.

These limitations, which result in fluctuations in nutrient levels, both in plant tissues and in the substrate, should be kept in mind. The analytic mehodology used (Page et al. 1982) follows.

Shoots and roots: Weekly sampling of 8 seedlings taken from their cavities with the substrate, chosen from diagonally across tables used exclusively for this purpose. Shoots and roots were separated, the material dried at 105°C

and then ground and mixed in a single representative sample for the week. The total elements of this sample were measured: N using Kjeldahl's method; P and K using $HClO_4$-HNO_3 digestion, colorimetric analysis of the phosphomolybdic complex (P) and spectophotometric analysis of atomic absorption (K).

Substrate: The substrate was air-dried at room temperature and ground before analysis for total N (Bremner and Mulvaney 1982); assimilable P (Bray and Kurts 1945); and exchangeable K (Schollenberger and Simon 1945).

Nitrogen

The nitrogen supply was ensured in early weeks by the application of 20-20-20, later reduced by half with 10-52-10 for the last four weeks of greenhouse cultivation. Quantities of fertilizer added varied from one period to another (Table 6); so did the method of application, as described in the section on fertilization.

The results (Figure 14a, 14b and 14c) show that root tissue is slightly richer in nitrogen than is the above-ground section, including stems. In both cases, a gradual decrease in nitrogen levels is observed over time. We also found a strong correlation between the nitrogen present in roots and in above-ground sections (Figure 14d). Variations in substrate levels are totally negligeable.

Table 6. Range of nitrogen fertilization used during different growth periods (mg/cavity)[1]

Period	20-20-20	N	10-52-10	N	N-total
Spr-81	211	42	109	11	53
Sum-81	165	33	85	8	41
Spr-82	122	24	63	6	30
Sum-82	152	30	78	8	38
Spr-83	185	37	95	10	47
Sum-83	205	41	105	11	52

[1] 19-week old seedling: 1 mg dry weight = 20 mg N.

This phenomenon can be explained; remember that our dosages were expressed in terms of total nitrogen, including the ammonia form but not the nitric nitrogen. The peat's initial nitrogen, which is mainly organic, masks the presence of the fertilizer when ammonia nitrogen and nitric nitrogen are dosed separately (Gonzalez 1981). Fluctuations observed may be attributed to the nature of the different lots of peat used. By way of example, we compared the N/P and N/K ratios reported by different authors (Ingestad 1962; Puustjärvi 1970; Callot et al. 1982) with those for our seedlings and found they were approximately the same, namely: 7-8 for N/P and 2.5 for N/K.

Phosphorus

This element was always added in soluble form in both fertilizers used. If the substrate is acidic, this anion is absorbed in its monovalent form $PO_4H_2^-$. In the above-ground sections and roots, phosphorous was measured in terms of total $P\text{-}PO_4^{-3}$, and in the substrate it was measured in available form (Bray and Kurtz 1945).

Despite the young age of the seedlings it was observed that more phosphorus was present in young tissues (6-8 weeks) than at the end of the growing period, both in needles and roots. This behavior is well known in agronomy (Gross 1960) and confirms that phosphorus is absorbed mainly during the period of active growth; later, during maturation, phosphorus is transferred to storage organs. We were unable to verify this stage of development because of the young age of our seedlings.

We did, however, note a greater level of P in the root system than in the above-ground section (Figure 15a, 15b and 15c). The direct relationship between changes in N and P in seedlings is noteworthy, with maximum levels coinciding on approximately the same dates. Correlation coefficients between the two element are highly significant, in the order of 0.80. A correlation also seems to exist between levels of P in above-ground and root sections (Figure 15d).

Given that the quantities of phosphorous supplied by each fertilizer are essentially the same (Table 7), the action of the 10-52-10 is more perceptible, probably because it is applied over a much shorter period (4 weeks) compared to the P from the 20-20-20 (8 weeks).

The buffer role played by the substrate in the stocking and availability

Table 7. Quantities of phosphorus supplied by each fertilizer (mg P/cavity)[1]

Growing period	(20-20-20)	(10-52-10)	Total P
SPR-81	18	25	43
SUM-81	14	19	33
SPR-82	11	14	25
SUM-82	13	18	31
SPR-83	16	22	38
SUM-83	18	24	42

[1] 19-week old seedling 1 g dry weight = 3 mg P

process mentioned above (soluble salts in the substrate) should also be mentioned. For a basic quantity of 9 g of dry weight (the average value of the substrate from a cavity), the range of P applied represented between 2 000 and 4 000 ppm of P and the P content of the substrate at the end of the growing periods was in the range of 1 000 ppm. A significant amount of the P applied, therefore, is retained by the peat and not released in available form by Bray and Kurtz extraction.

Potassium

Potassium was added in soluble form (nitrate or monobasic phosphate) in both fertilizers used. Although some of the mechanisms in which potassium plays a role are not clearly defined physiologically, no doubt remains as to the importance of this nutrient in plant nutrition. It contributes to water conservation by reducing transpiration; it improves frost resistance; and, it improves harvest under unfavorable sunlight conditions.

Both in the above-ground and root sections, a trend similar to that for the two other major nutrients already analysed, N and P, was noted, namely, that potassium levels tend to drop off progressively with seedling age.

In general, root tissues show a slightly higher level of K than above-ground tissues (Figures 16a, 16b and 16c). However, this difference is not as marked as in the case of N and P. We also noted that potassium is significantly correlated to nitrogen in the tissues analyzed (Figure 16d).

Since the initial level of exchangeable K in the substrate is relatively low (1.2 meq/100 g or 0.04 %), the addition of the 20-20-20 produced a sharp change during the 5th-6th week, with maximum values achieved during the use of this fertilizer. When the 10-52-10 was applied, a progressive drop in the substrate potassium level was observed.

We believe that the supply of potassium satisfied the needs of the seedlings (Table 8); analytic results confirm this conclusion and no visual symtoms of deficiency developed in the foliage.

It appears that no real possibility of a potassium accumulation hindering seedling development exists, given the nature of the substrate. The properties of the humus fraction of the peat allows

Table 8. Quantities of potassium supplied by each fertilizer (mg K/cavity)[1]

Growing period	(20-20-20)	(10-52-10)	Total K
Spr-81[2]	35	9	44
Sum-81[3]	27	7	34
Spr-82	20	5	25
Sum-82	25	6	31
Spr-83	31	8	39
Sum-83	34	9	43

[1] 19-week old seedling 1 g of dry weight = 10 mg K

[2] Spr = Spring [3] Sum = Summer

the retention of exchangeable form avoiding the retrogradation phenomenon observed in clay soils.

As indicated above, a ratio exists in the accumulation of N and P for the above-ground and root sections (Figures 14d and 15d). In addition, it appears that the distribution of these nutrients is also modified by two environmental factors. First, the N and P accumulation in the root section depends on the concentration of these elements in the rooting subtrate (Figure 17); second, the N and P accumulation in the above-ground section is function of the total number of degree-days during the growing period (Figure 18).

CONCLUSIONS

Observations noted and measurements taken over six growing periods were designed to provide data on the method of obtaining biological material deemed adequate, and to provide a better understanding of the factors involved in containerized seedling production, a process that is both very simple and very complex.

First, the production area, a conventional glass greenhouse, certainly showed us the limits of such installations for carrying out research projects: insufficient uniformity in watering and fertilization and abrupt changes in relative humidity and temperature.

Large-scale producers should keep these factors in mind in order to avoid unpleasant surprises. During the summer period, particular care must be taken given excessive temperatures (40°C) which, despite ventilation, could compromise production. In this regard, we seriously question the usefulness of non-air-conditioned glass-covered greenhouses during summer.

The relative humidity of the air is still one of the most difficult factors to measure precisely. It would therefore be futile to try to control it inside a large greenhouse. Nevertheless, precautions should be taken to avoid sudden drops in relative humidity following periods of intense heat by using adequate misting equipment.

Since the level of radiant energy is unpredictable, the usefulness of a supplementary lighting system should be assessed to compensate for a possible shortage of sunlight which would almost inevitably slow growth. Minimum lighting is necessary to ensure a long photoperiod and prevent the seedlings from becoming dormant.

Turning to morphology, although we produced acceptable seedlings, it should be noted that the growth and available energy level is not always positive. Excess heat seems to be responsible for growth loss in black spruce seedlings under the growing conditions in our greenhouse.

Since fertilization is generally coupled with the watering system, we must ensure that distribution is uniform in order to avoid having certain strips of seedlings systematically underfertilized or overfertilized. Periodic rotation of the containers improves production uniformity. Following germination, the water content of the substrate should be about 60 to 70 percent of saturation for the remainder of the production period.

One of the most controversial issues in seedling production is fertilization, both in terms of the type of fertilizer used and the amount and method of application. These two factors can be combined in an infinite number of ways. After a thorough review of the literature, we opted for 20-20-20 and 10-52-10. The different methods of application and the doses tested did not significantly affect seedling morphology. We are increasingly convinced that if we keep away from extreme values, which may produce deficiencies or toxicity, the margin of confidence in fertilizer application will be relatively high. On the other hand, the higher the concentration, the more likely is there to be an accumulation of nutrients in the roots.

This safety margin is further assured by the peat's ionic retention capacity. This capacity came to our attention in our observations on soluble salts. Particularly, during summer 1982, we noted a reduction in the dry weight and height of our seedlings compared to other periods. But that would more likely be due to the temperatures above 40°C recorded over several days, and not to fertilization problems.

Finally, foliar analysis showed a gradual decrease, overtime, in the concentration of nutrient elements. These elements are more abundant in the root system than in the above-ground portion. Further study is needed to determine whether this accumulation in the roots is due to the concentration and/or an ontogenetic change.

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APPENDIX

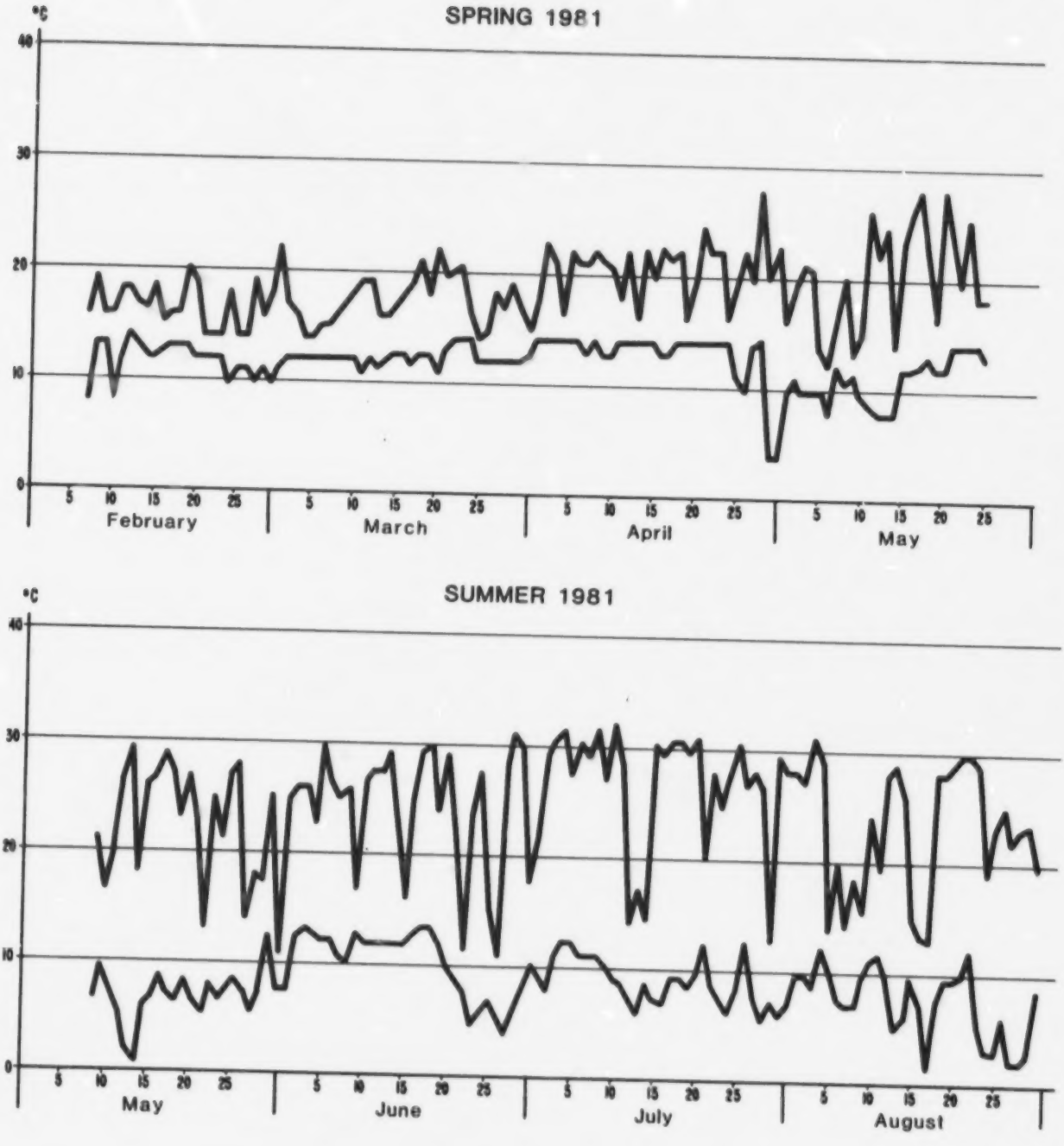

Figure 1a. Daily maximum and minimum temperatures recorded under greenhouse conditions during the 1981 production periods.

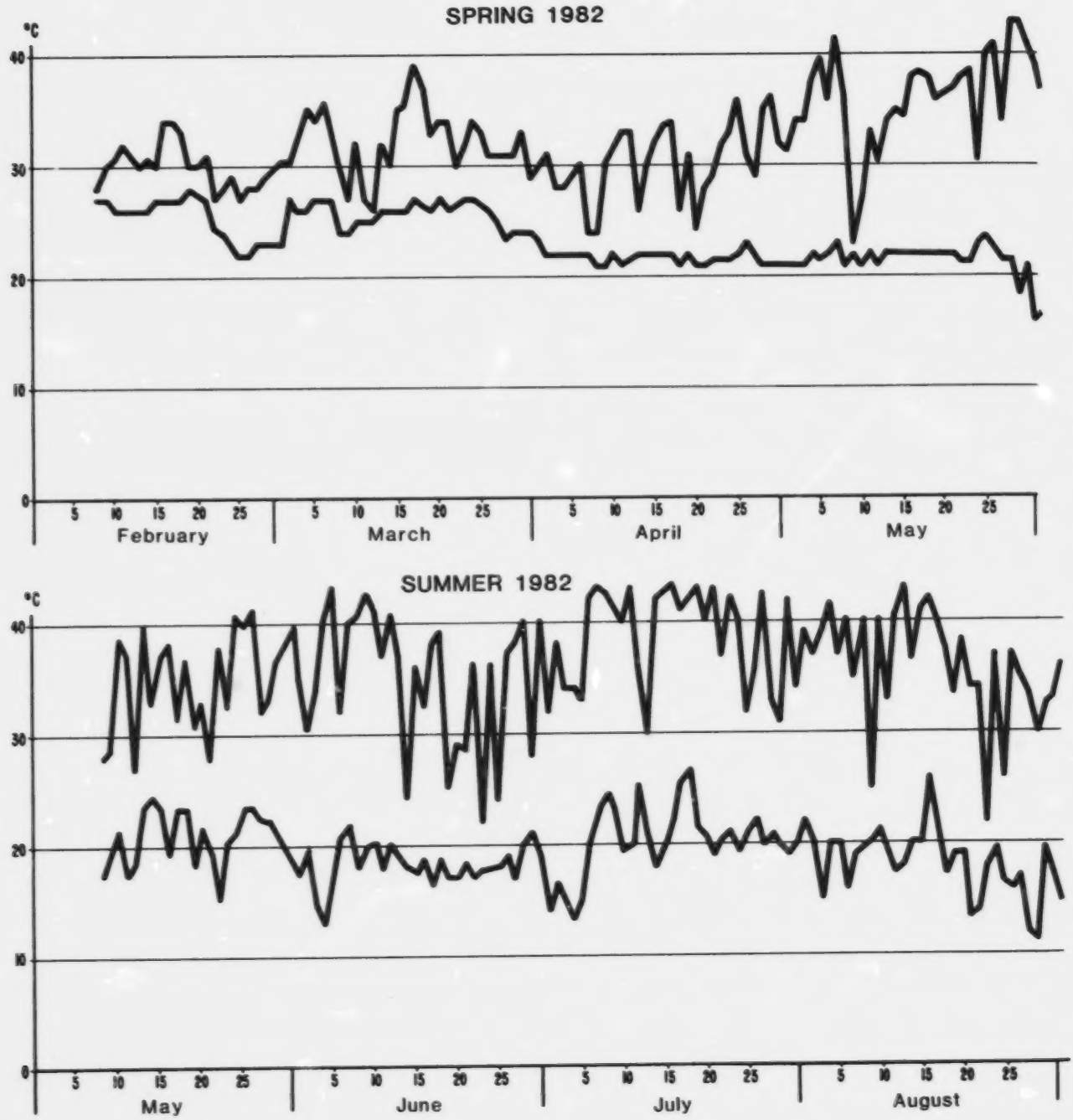

Figure 1b. Daily maximum and minimum temperatures recorded under greenhouse conditions during the 1982 production periods.

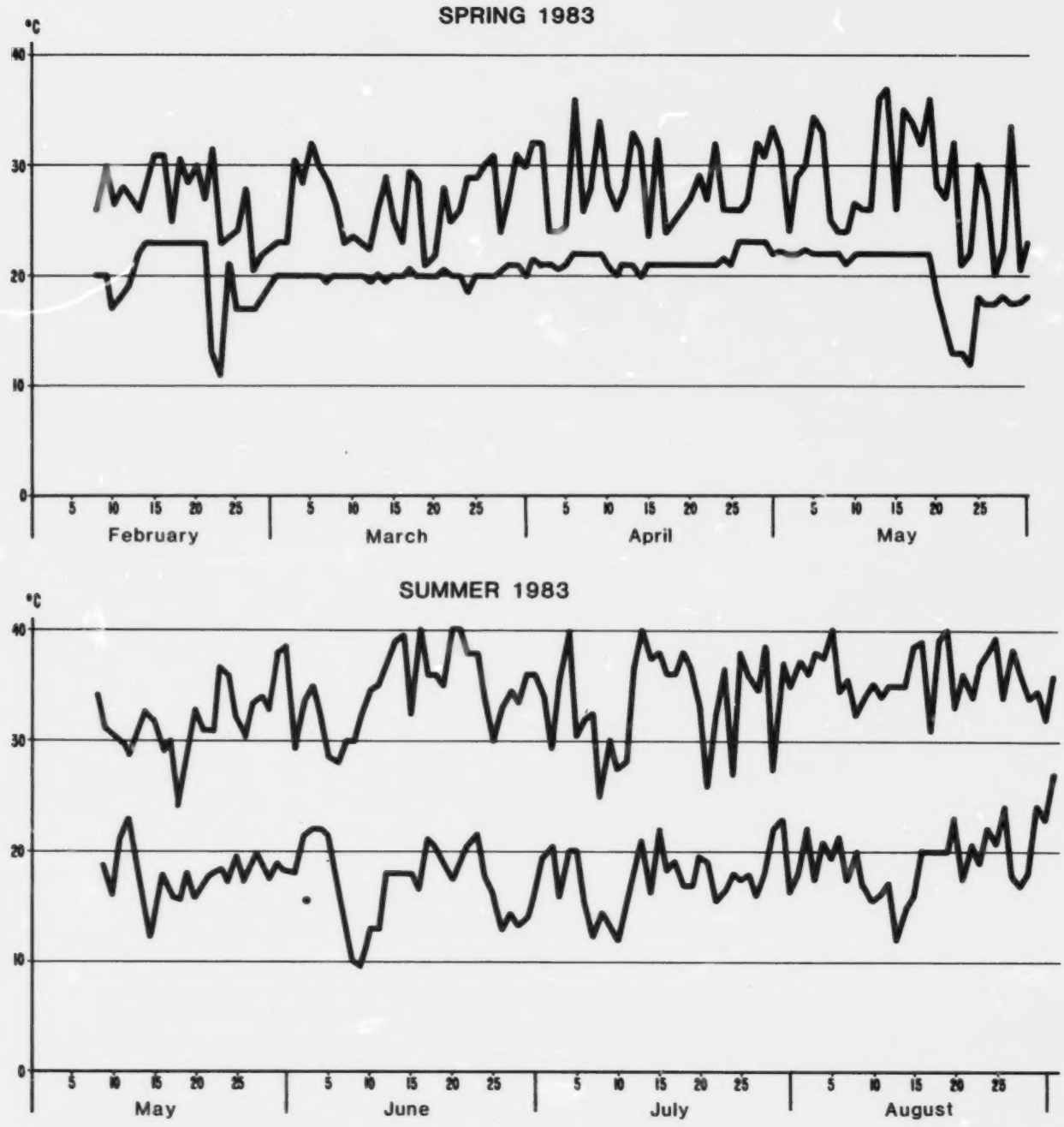

Figure 1c. Daily maximum and minimum temperatures recorded under greenhouse conditions during 1983 production periods.

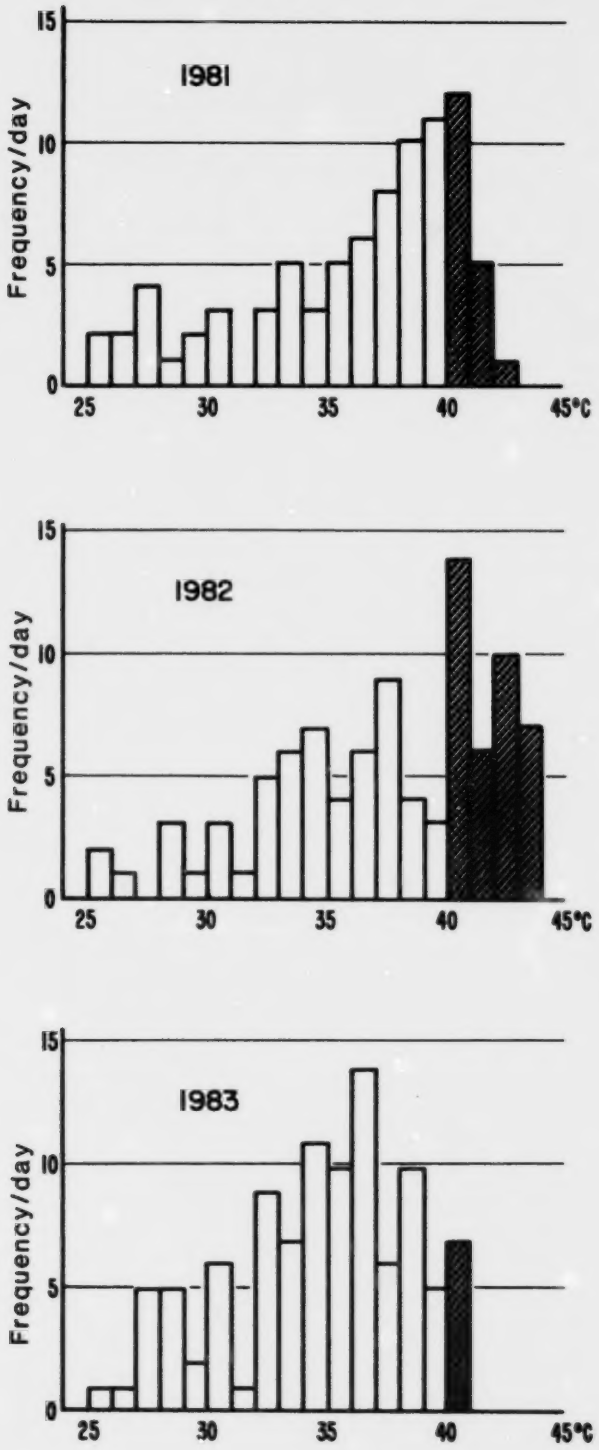

Figure 1d. Daily frequency of maximum temperatures during the 1981, 1982, and 1983 summer periods (June, July, August).

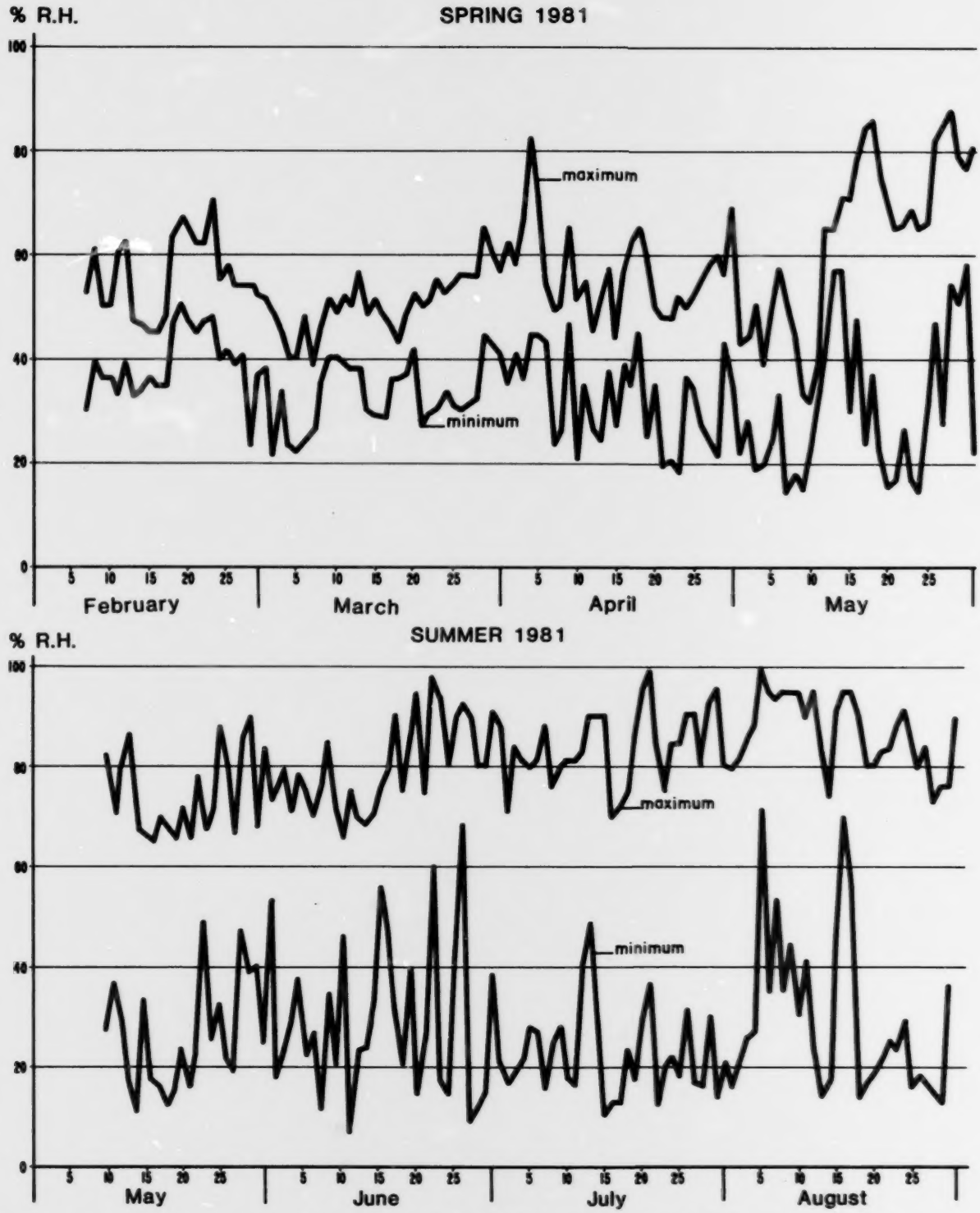

Figure 2a. Relative humidity of the air (daily maximum and minimum) recorded under greenhouse conditions during the 1981 production periods.

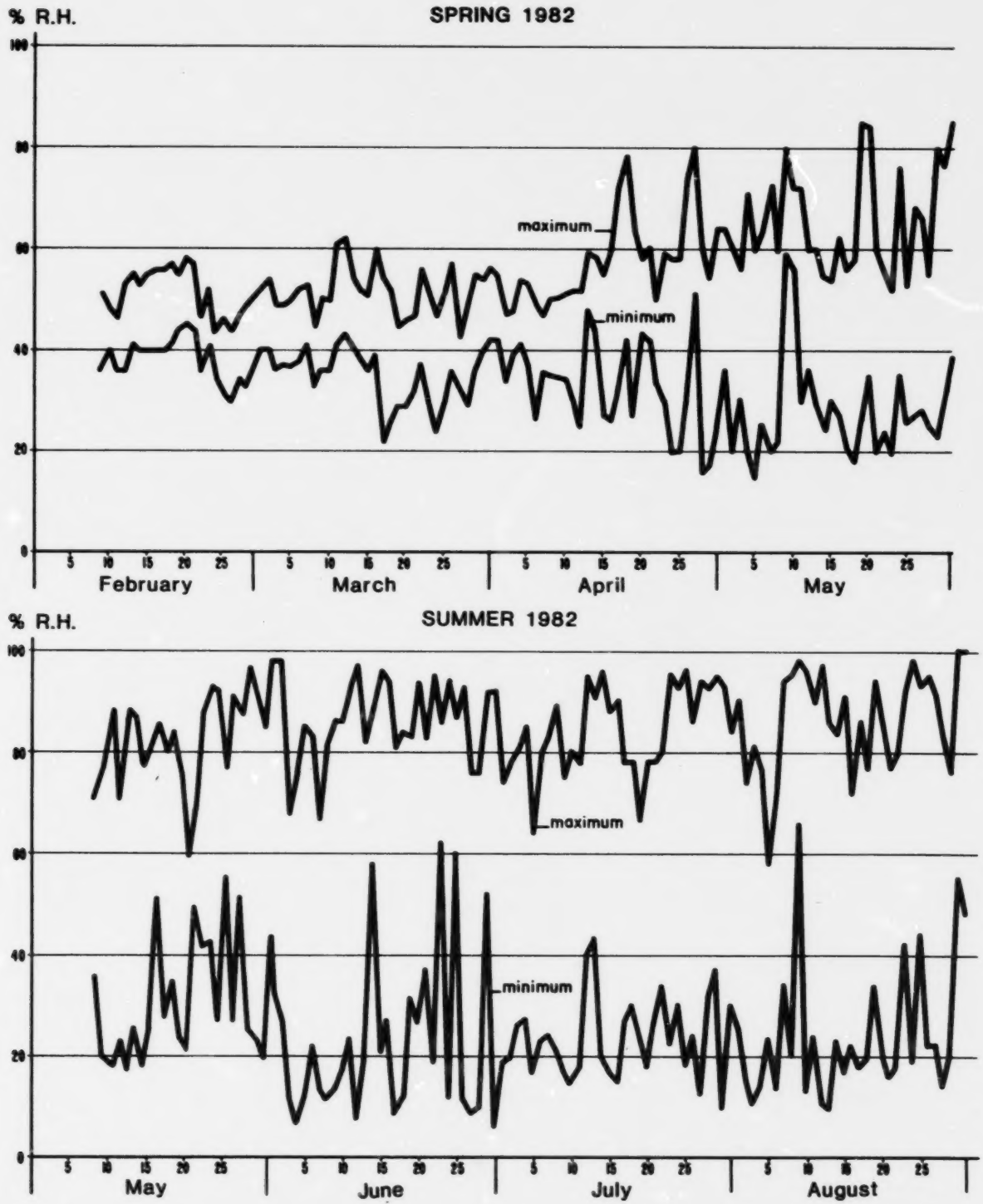

Figure 2b. Relative humidity of the air (daily maximum and minimum) recorded under greenhouse contions during the 1982 production periods.

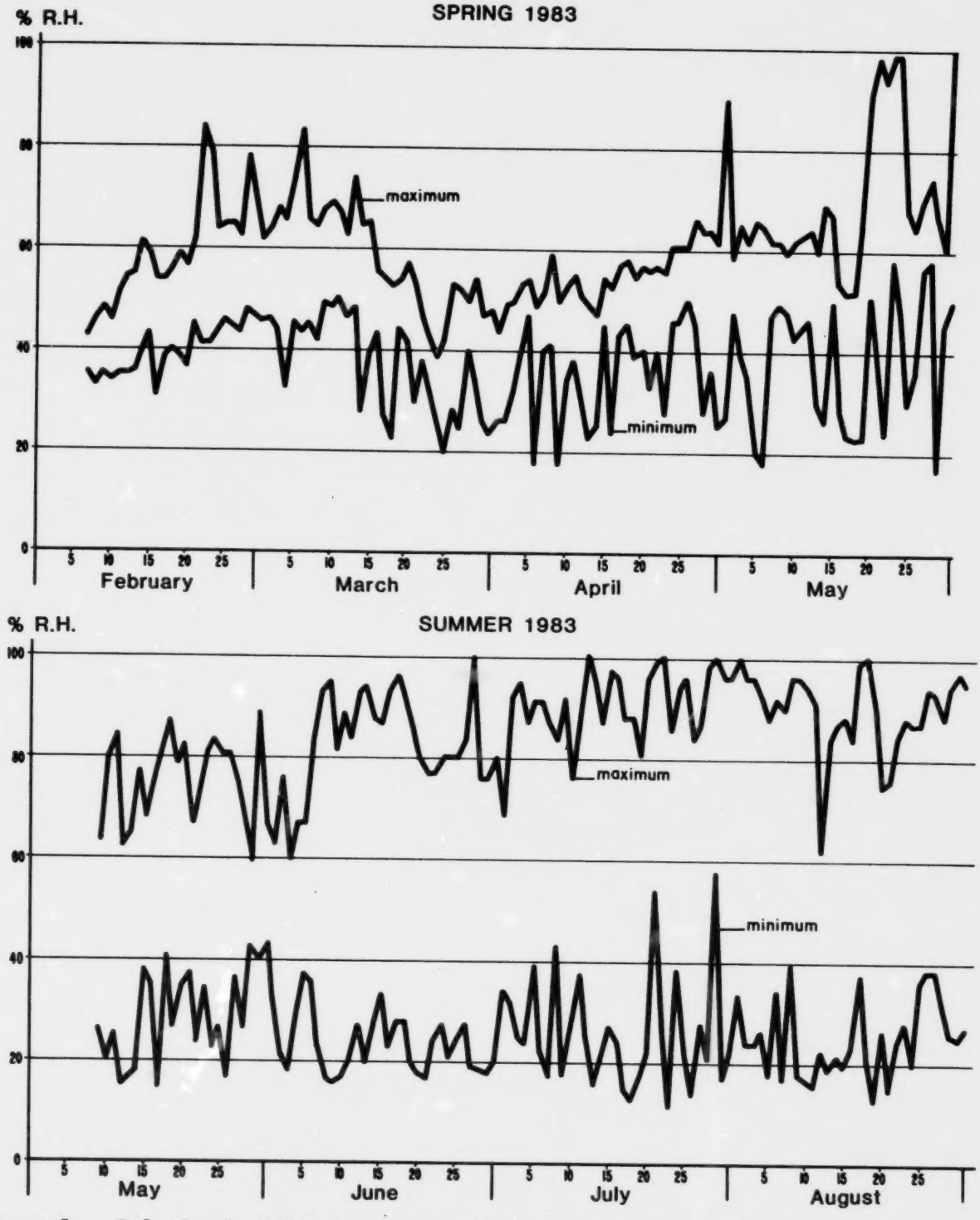

Figure 2c. Relative humidity of the air (daily maximum and minimum) recorded under greenhouse conditions during the 1983 production periods.

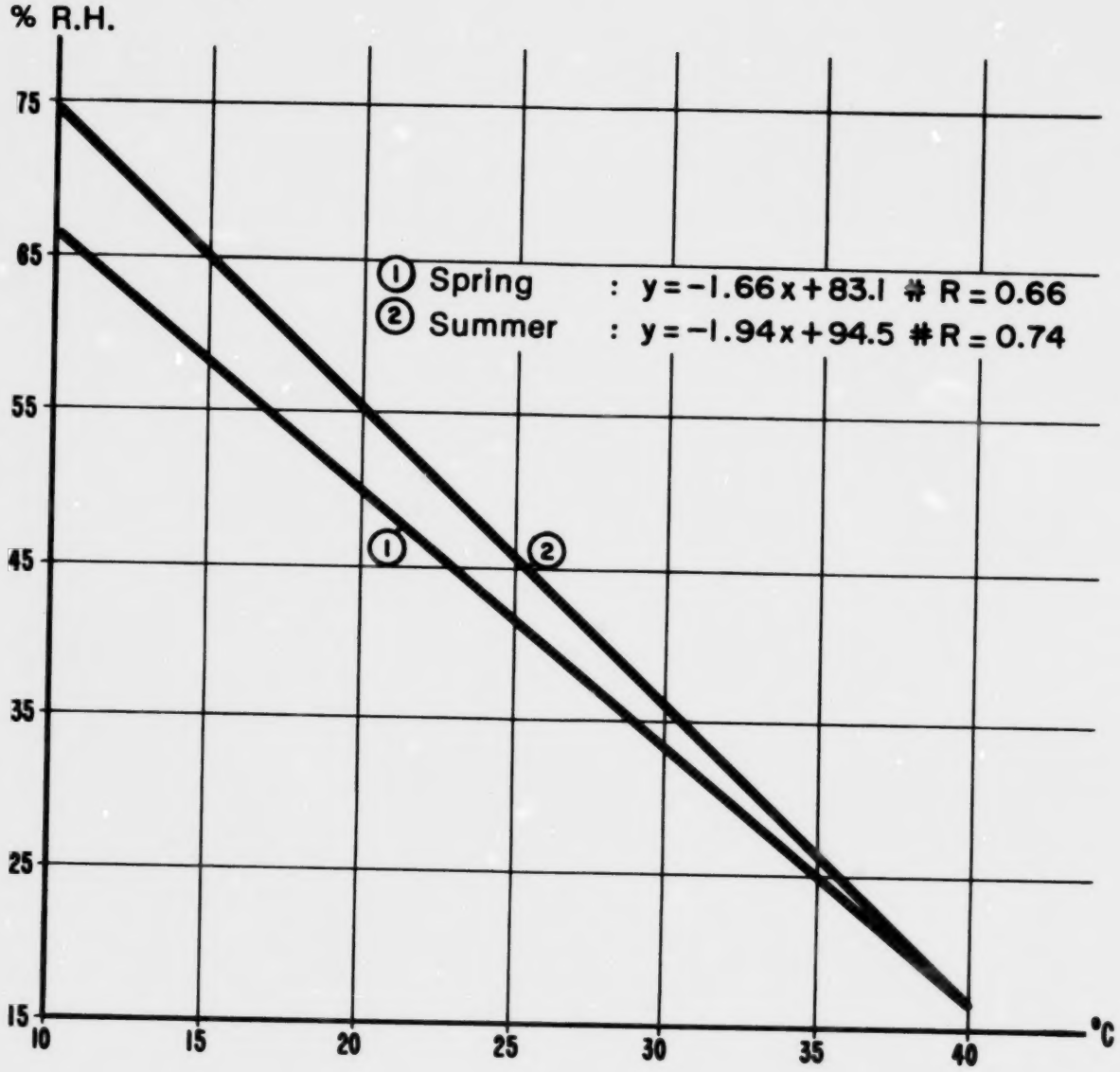

Figure 2d. Maximum daily temperatures vs. minimum relative humidity (average for 1981, 1982, 1983).

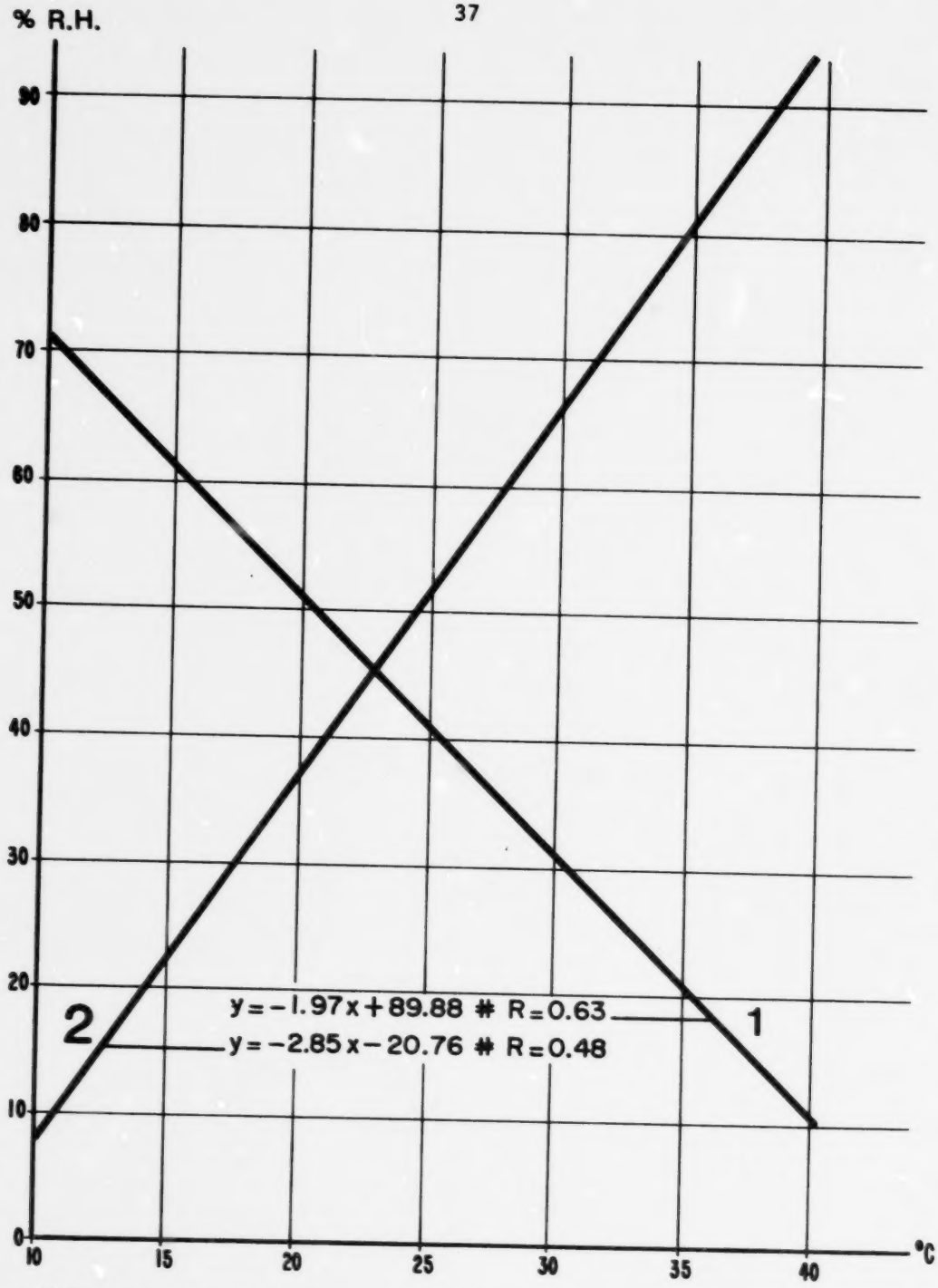

Figure 2e. Values for temperatures and of the air relative humidity recorded with a micrologger and taken in a "synchronized" manner (spring 1984).

1. Maximum daily temperatures
2. Minimum daily temperatures

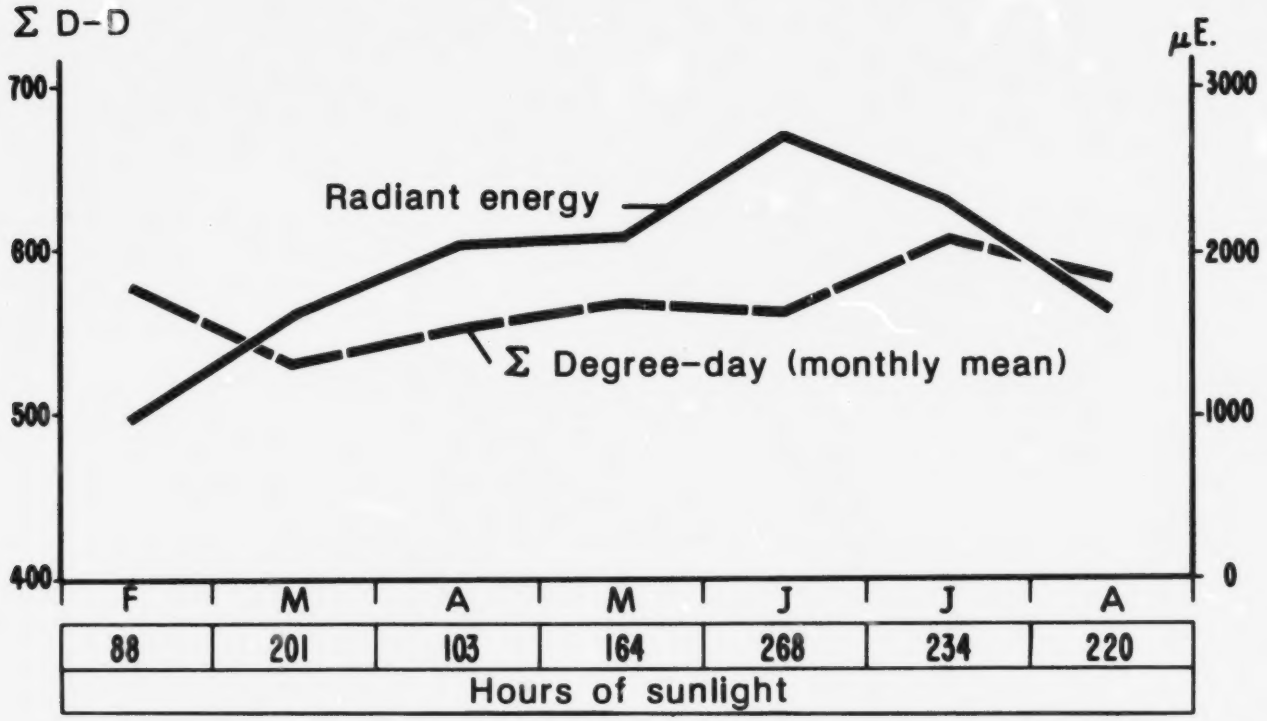

Figure 3. Radiant energy and growing degree-days recorded under greenhouse conditions with a CR-21 micrologger (production periods: 1984).

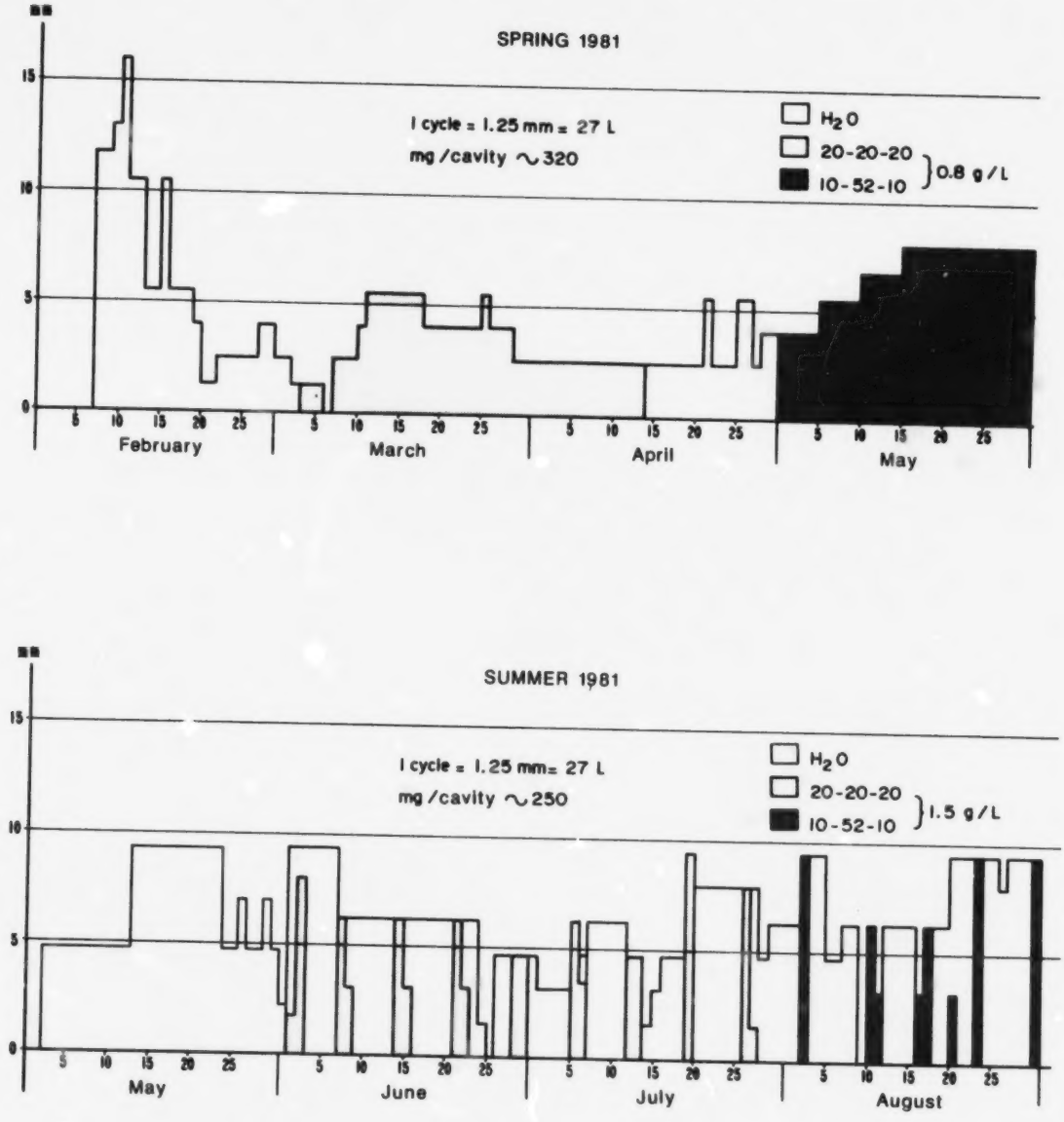

Figure 4a. Schedule and methods of watering and fertilization for the 1981 production periods.

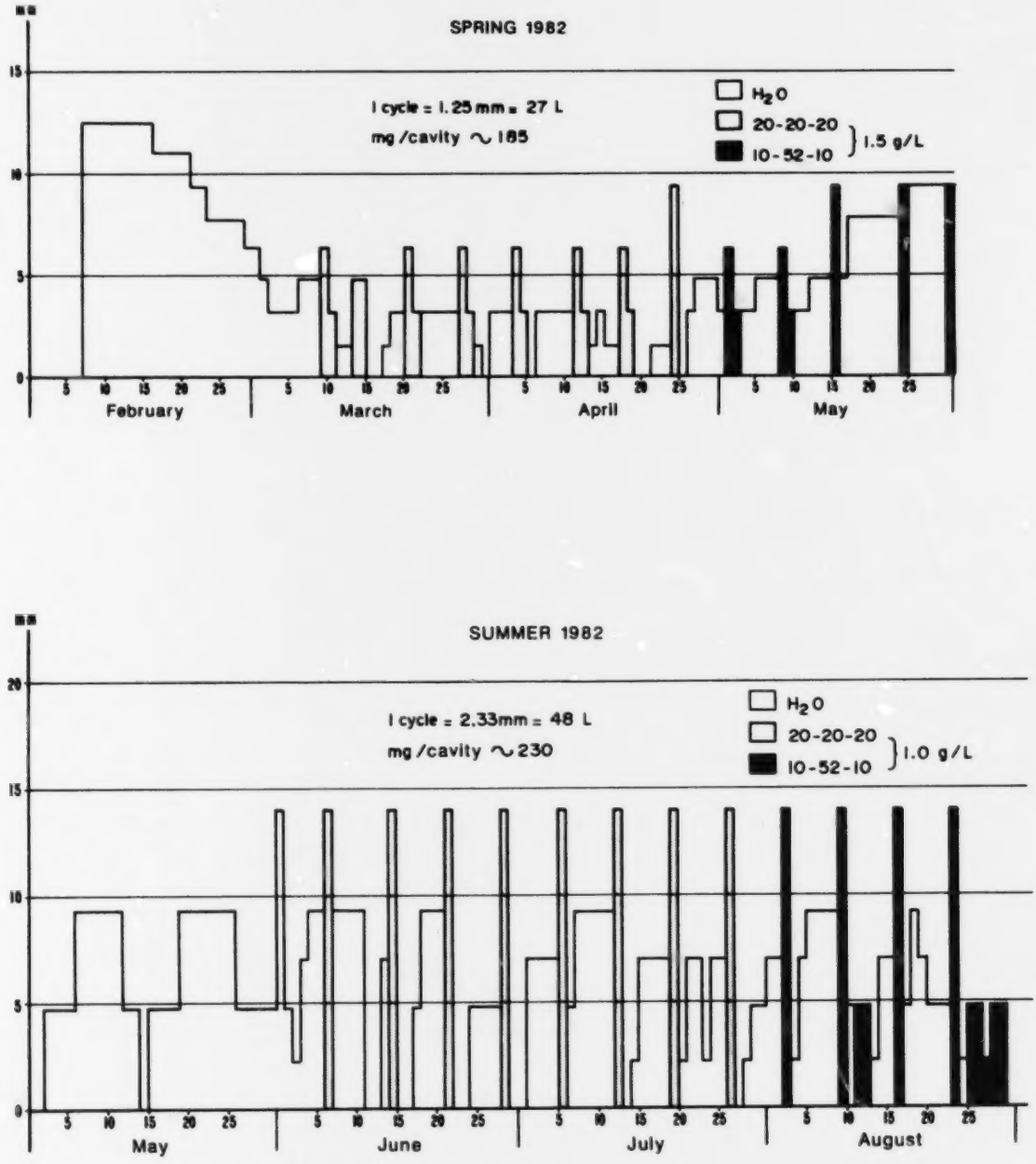

Figure 4b. Schedule and methods of watering and fertilization for the 1982 production periods.

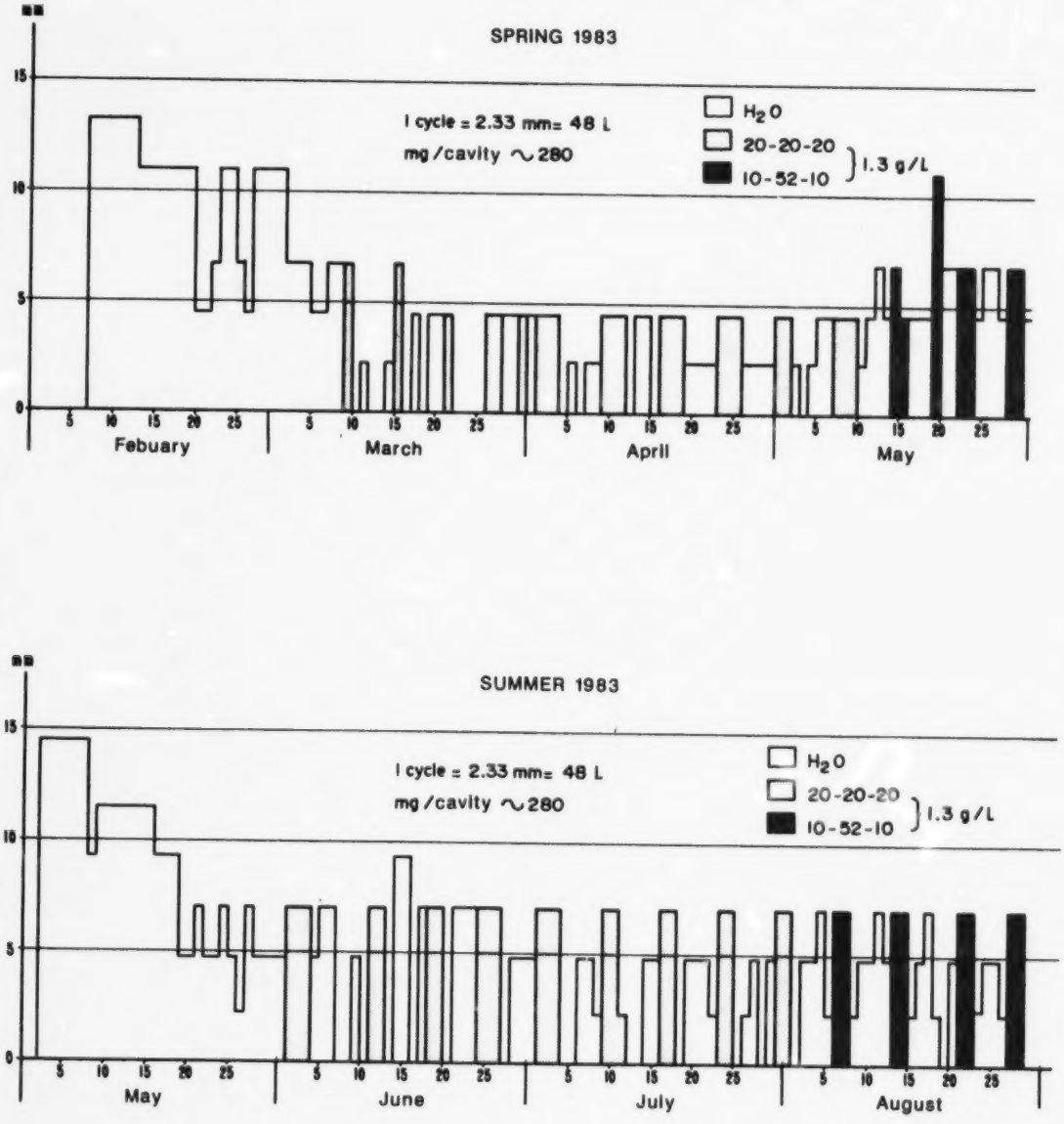

Figure 4c. Schedule and methods of watering and fertilization for the 1983 production periods.

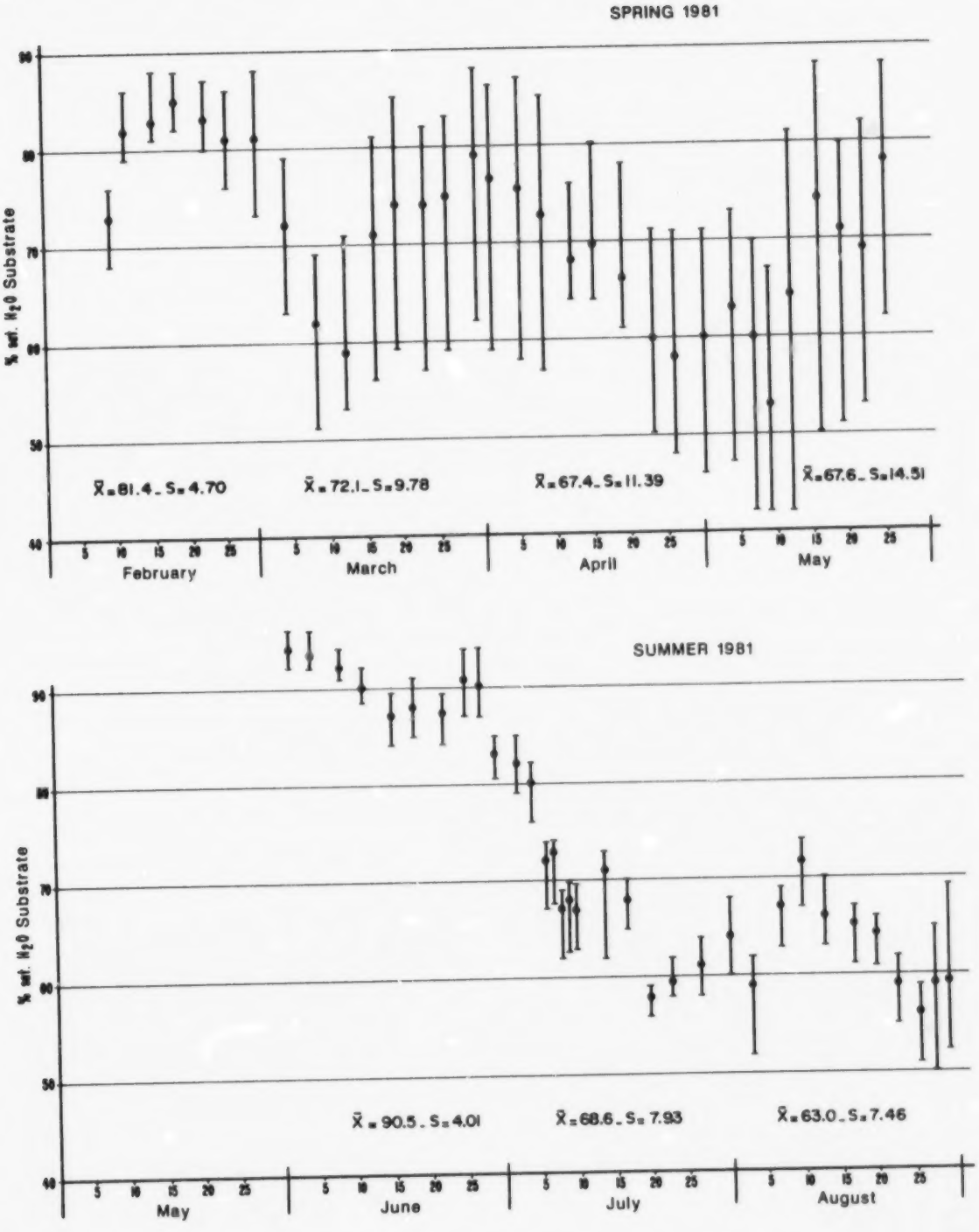

Figure 5a. Variations in the water content of the substrate during the 1981 production periods.

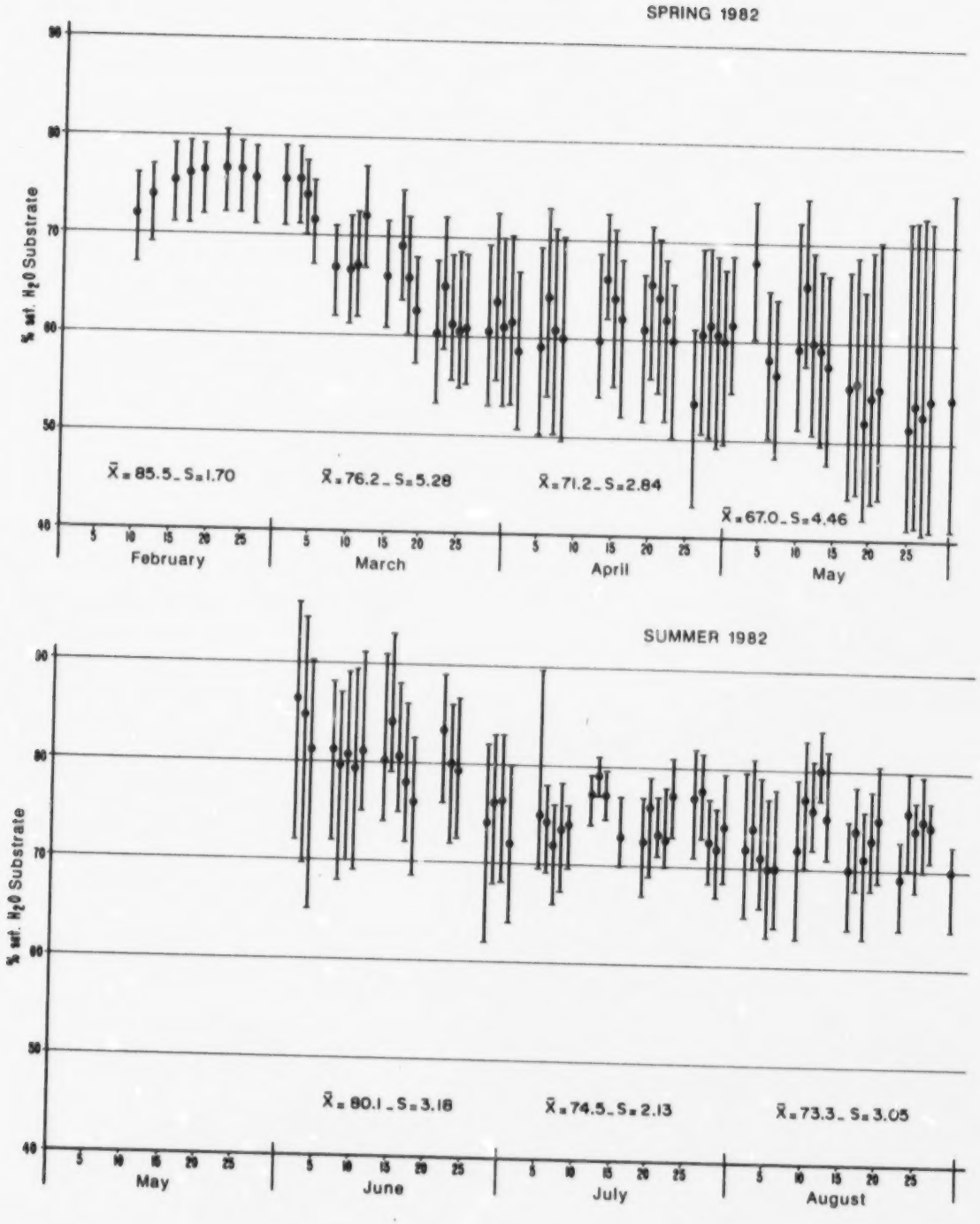

Figure 5b. Variations in the water content of the substrate during the 1982 production periods.

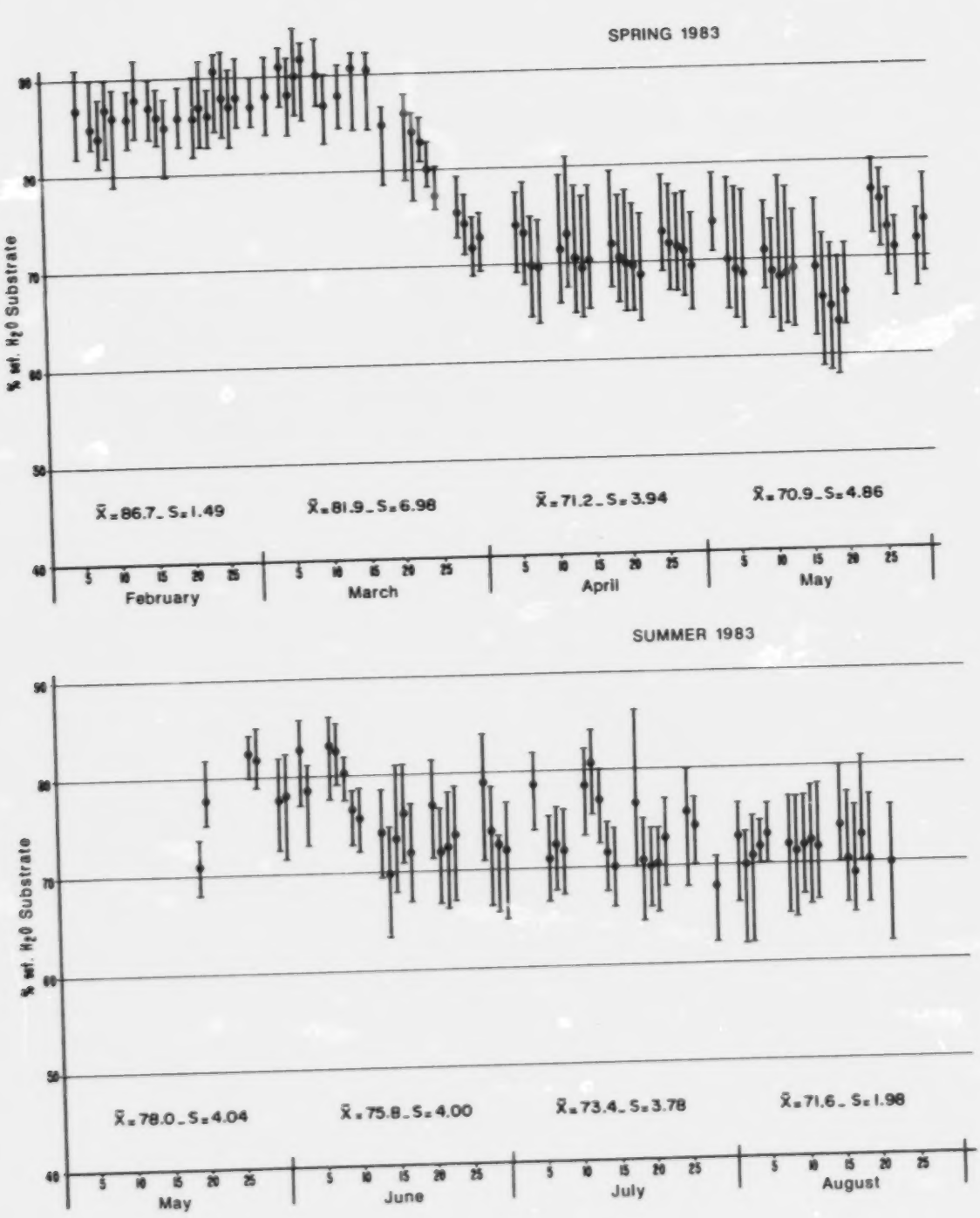

Figure 5c. Variations in the water content of the substrate during the 1983 production periods.

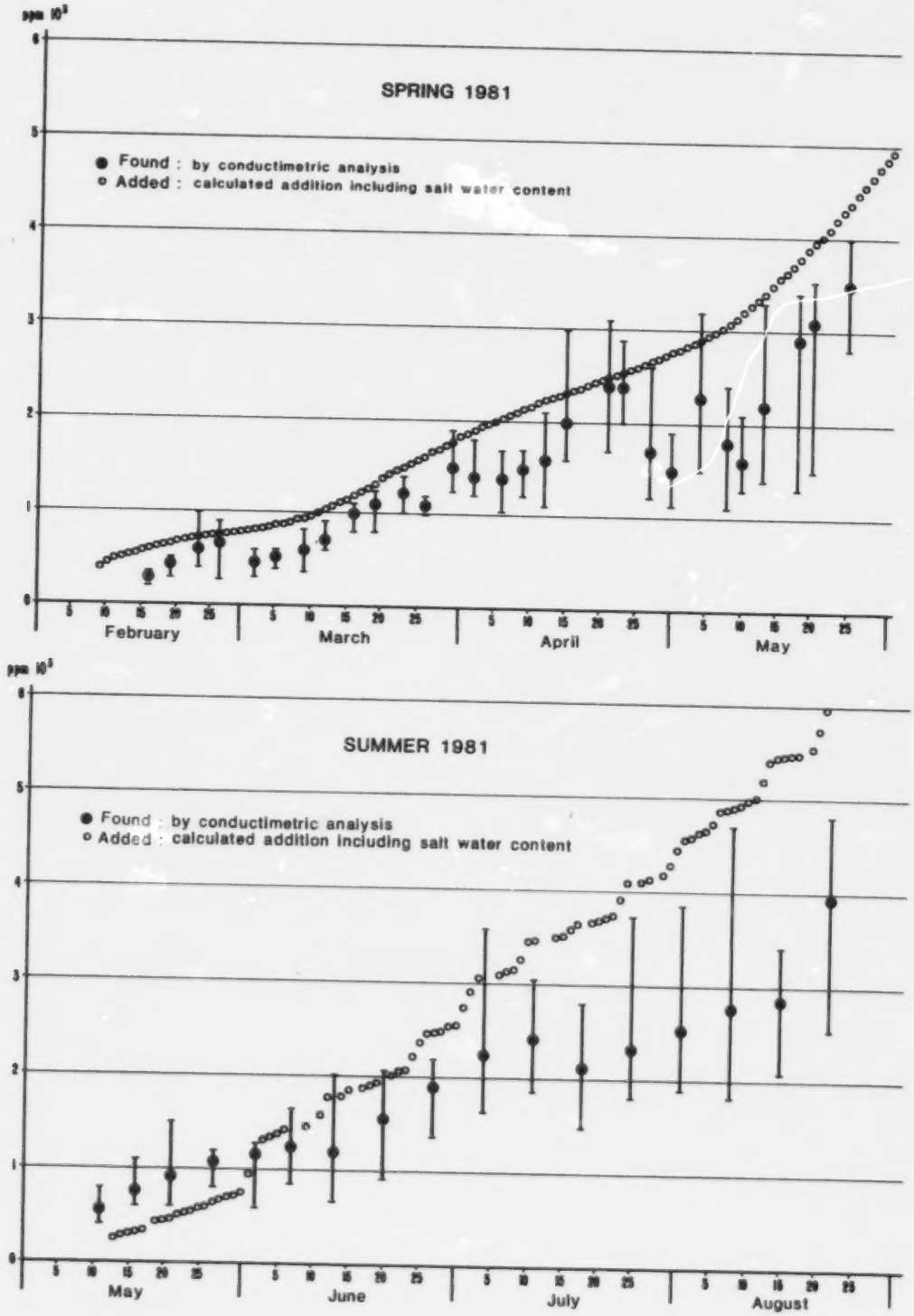

Figure 6a. Concentrations of soluble salts for the volume of water in a container, for a given water content (1981).

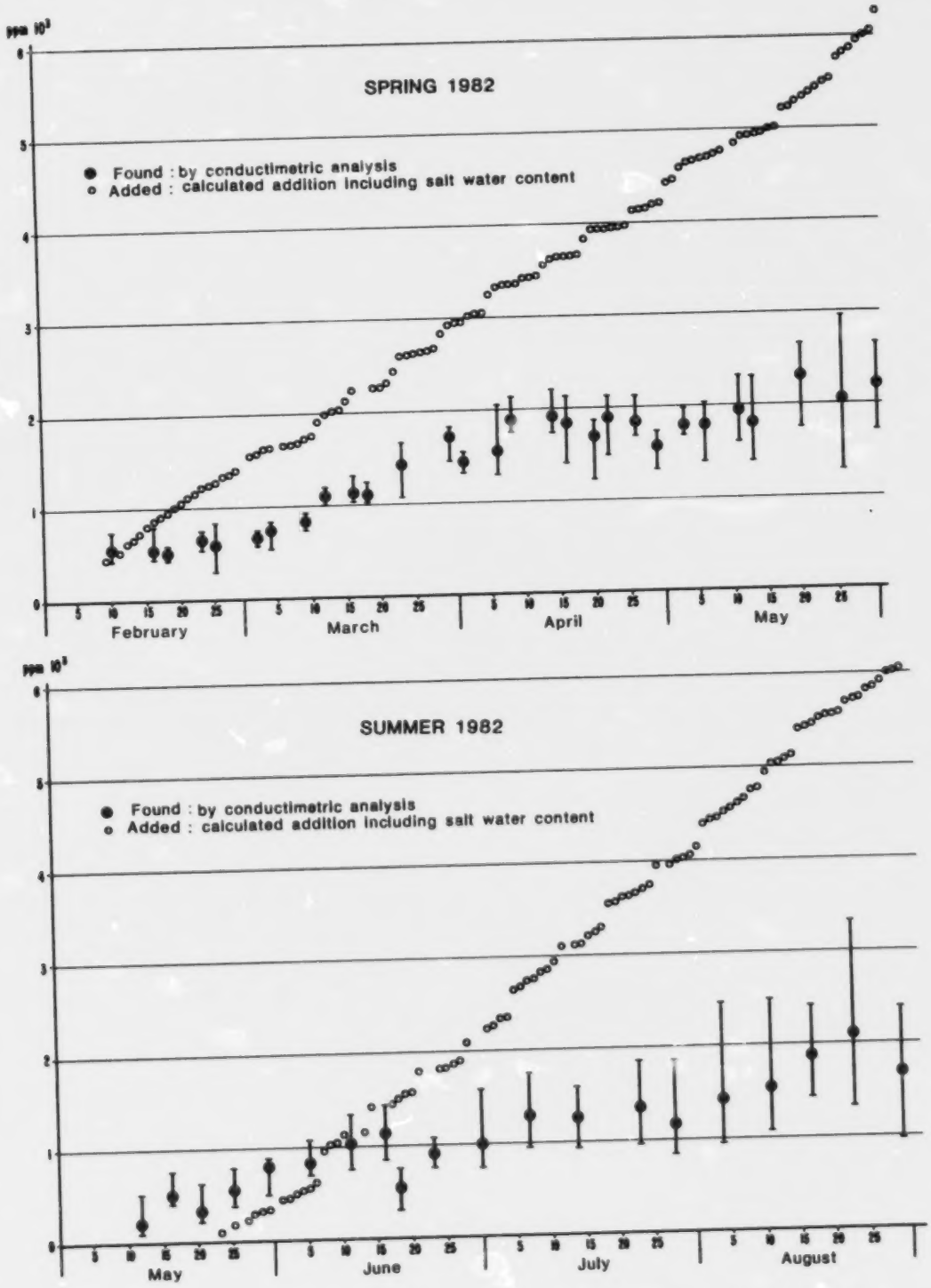

Figure 6b: Concentrations of soluble salts for the volume of water in a container, for a given water content (1982).

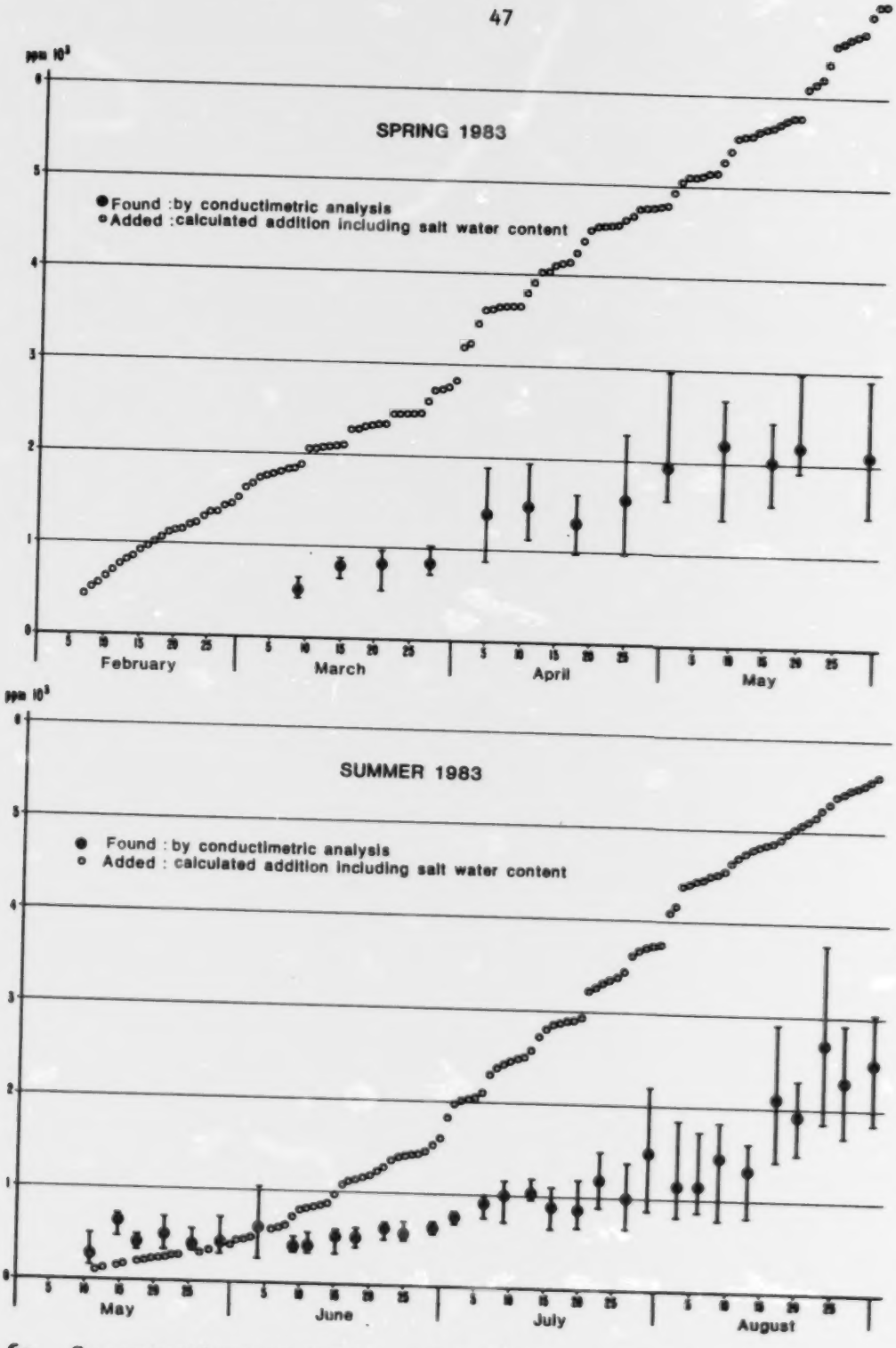

Figure 6c. Concentrations of soluble salts for the volume of water in a container, for a given water content (1983).

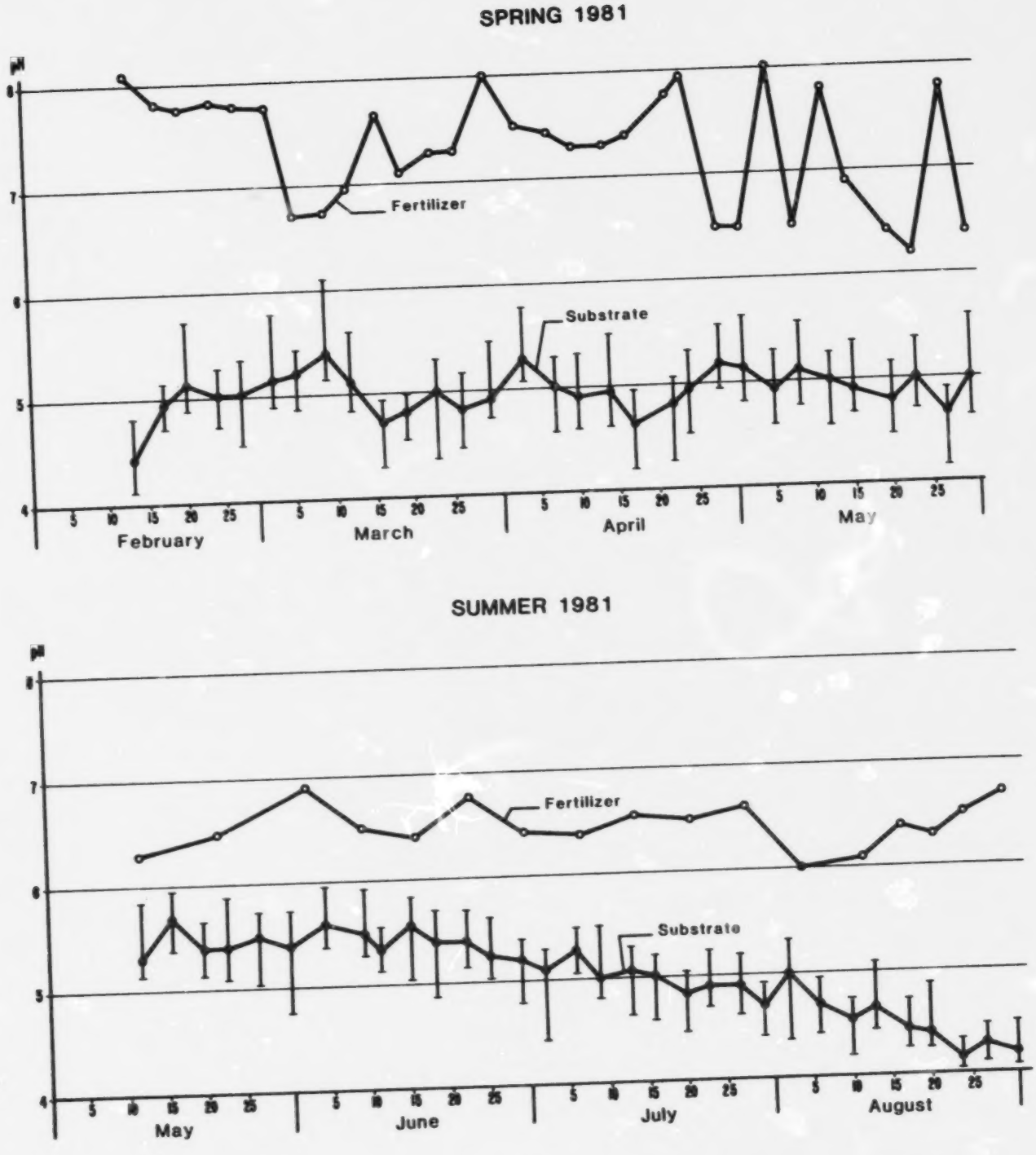

Figure 7a. pH values in the fertilizer solution and of the substrate during the 1981 production periods.

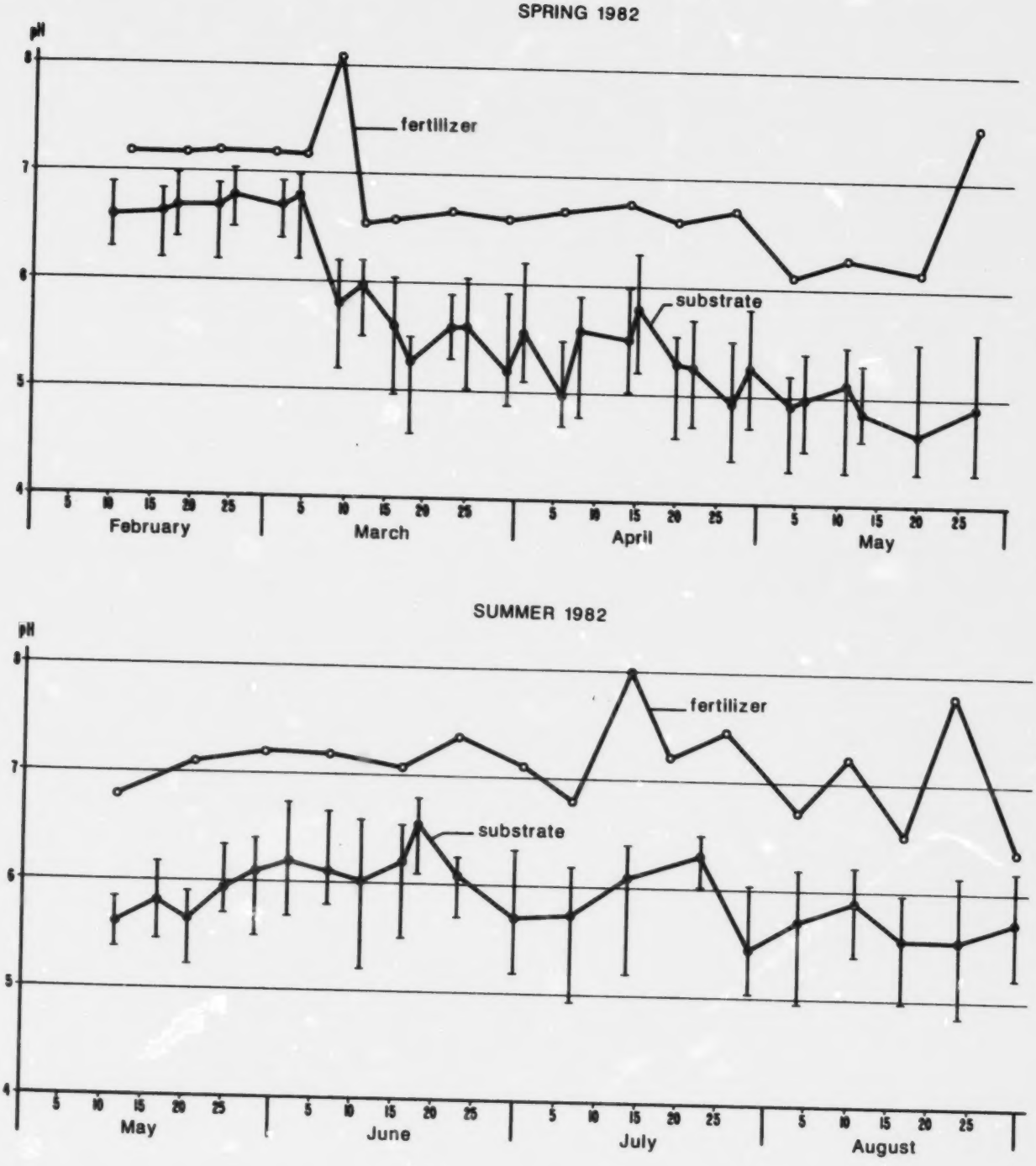

Figure 7b. pH values in the fertilizer solution and of the substrate during the 1982 production periods.

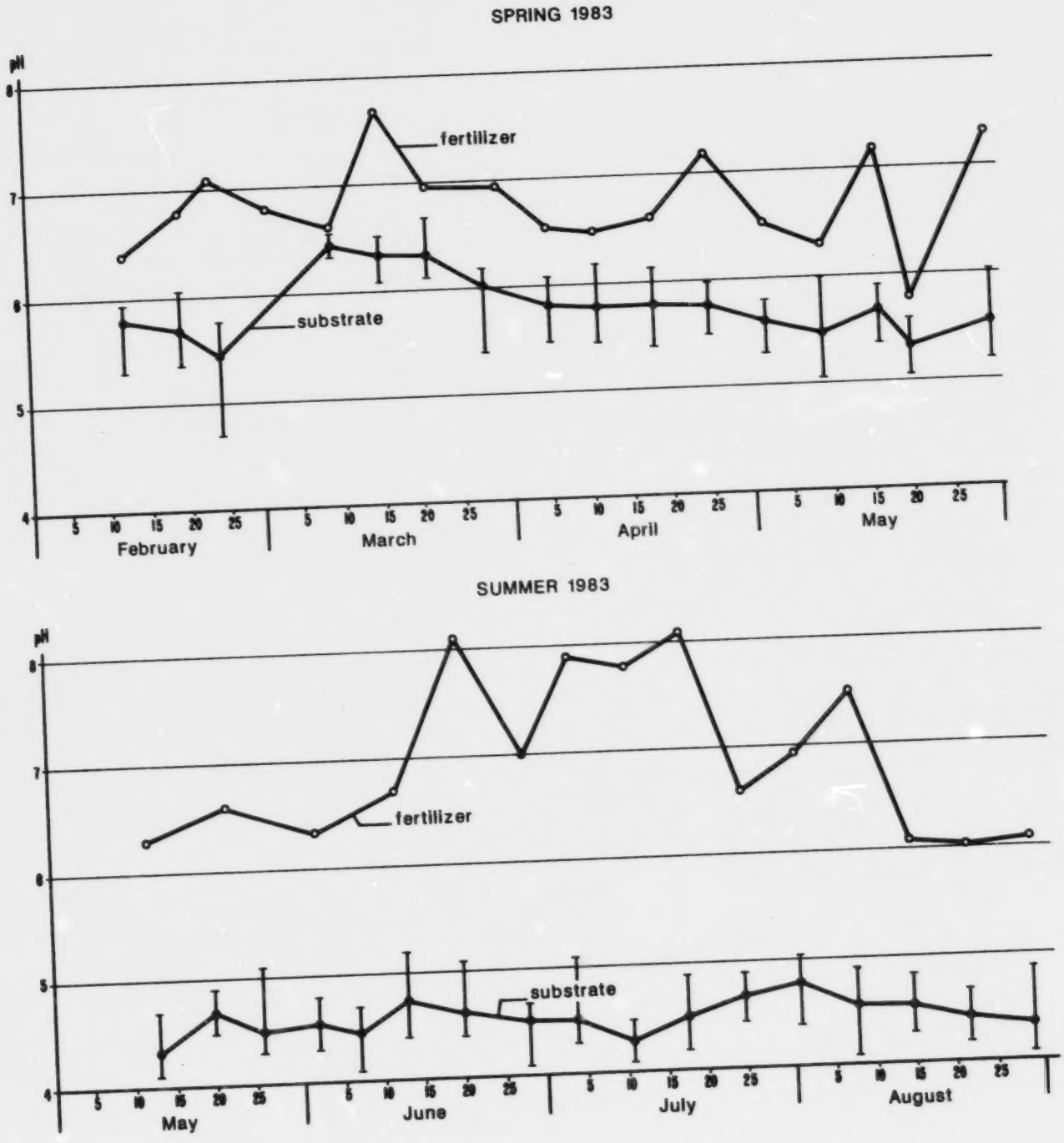

Figure 7c. pH values in the fertilizer solution and of the substrate during the 1983 production periods.

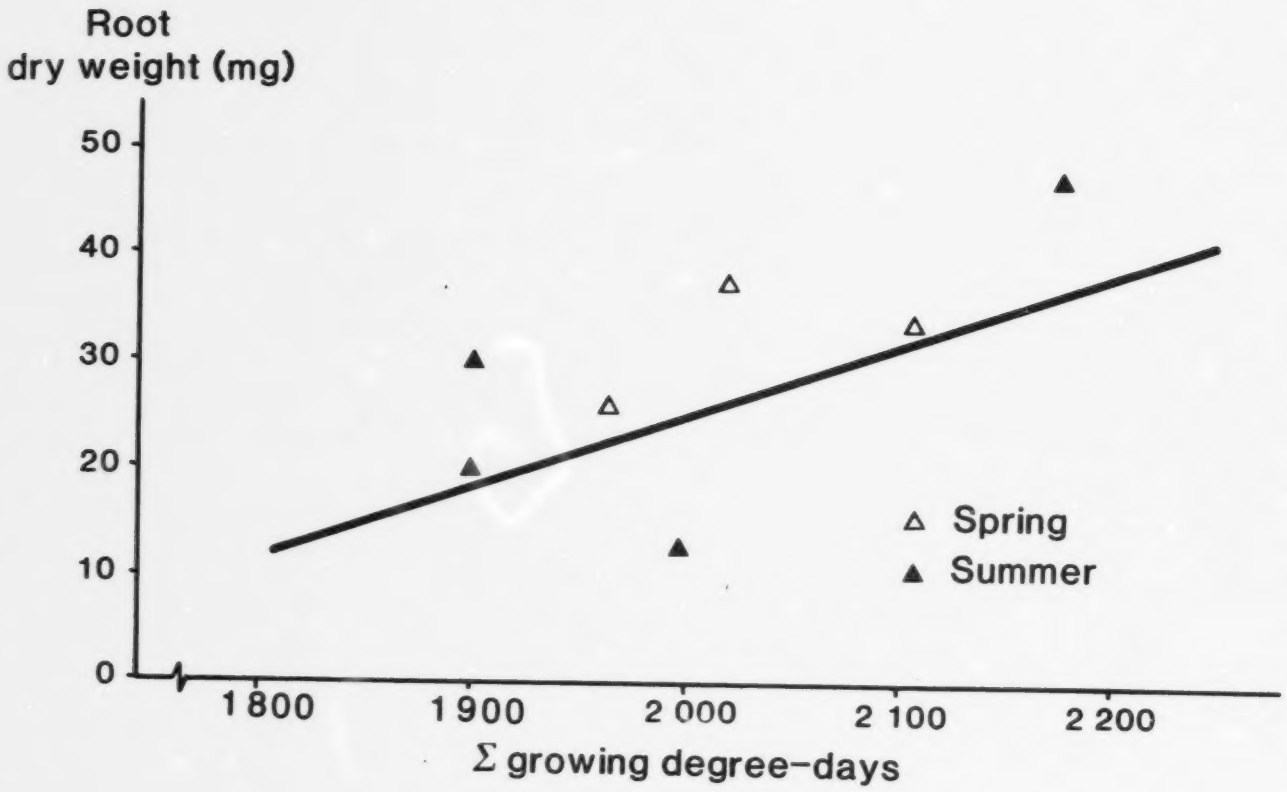

Figure 8. Root growth in black spruce seedlings, after 15 weeks under greenhouse conditions. Values represent the averages for a minimum of 16 seedlings and a maximum of 50, for 4 consecutive years and 2 production periods. The line represents the approximate average.

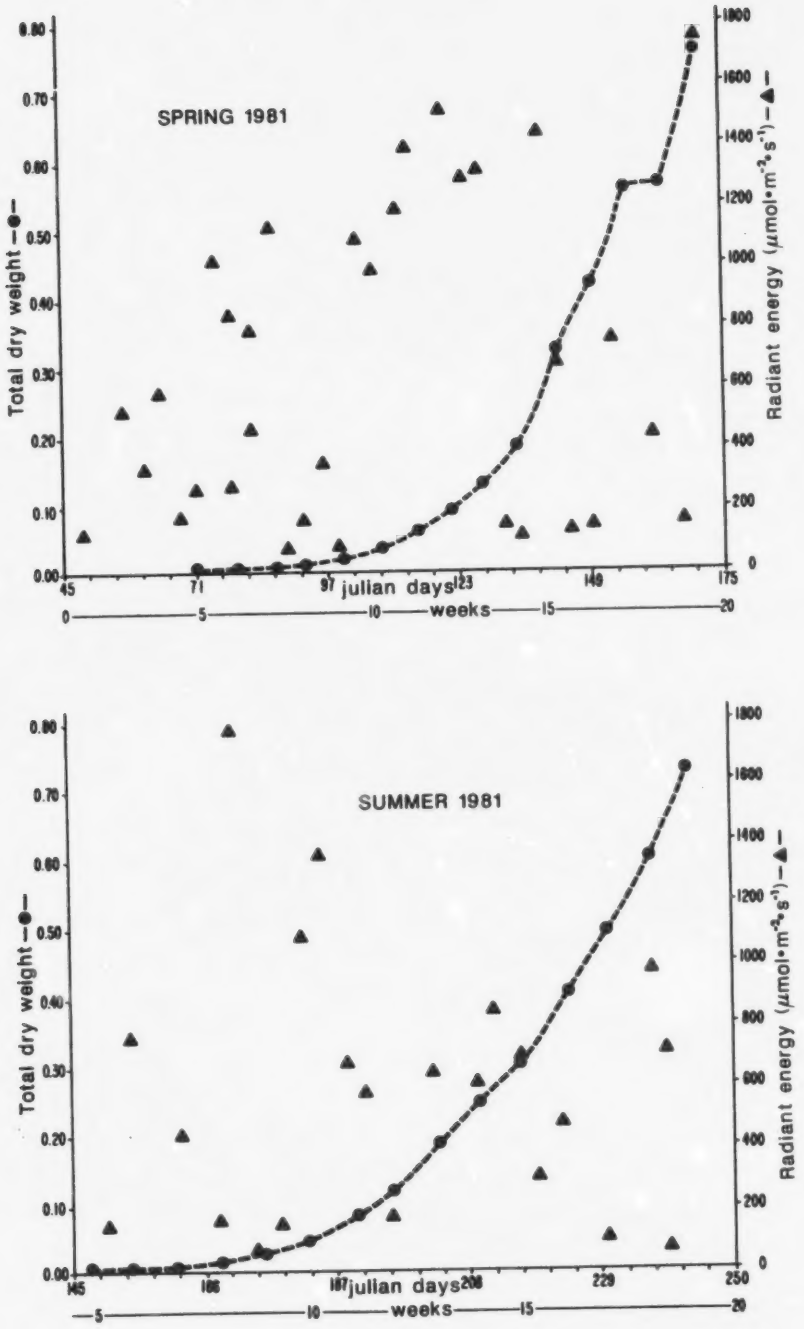

Figure 9. Periodic radiant energy, recorded at noon and accumulation of dry weight in black spruce seedlings grown under greenhouse conditions.

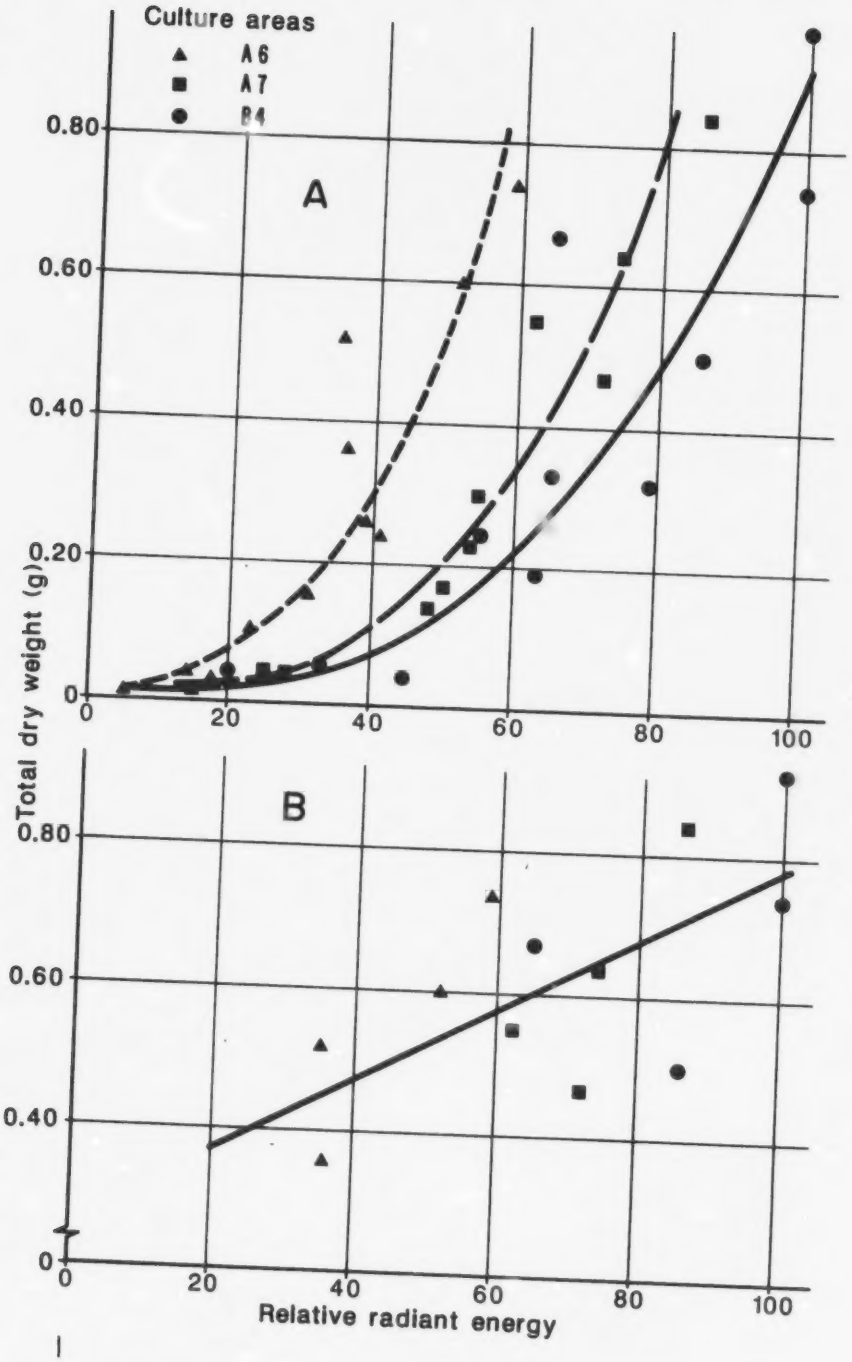

Figure 10. A: Growth of seedlings as a function of the relative radiant energy of 3 production areas. B: Total accumulation of dry weight in terms of relative radiant energy after 20 weeks of growth.

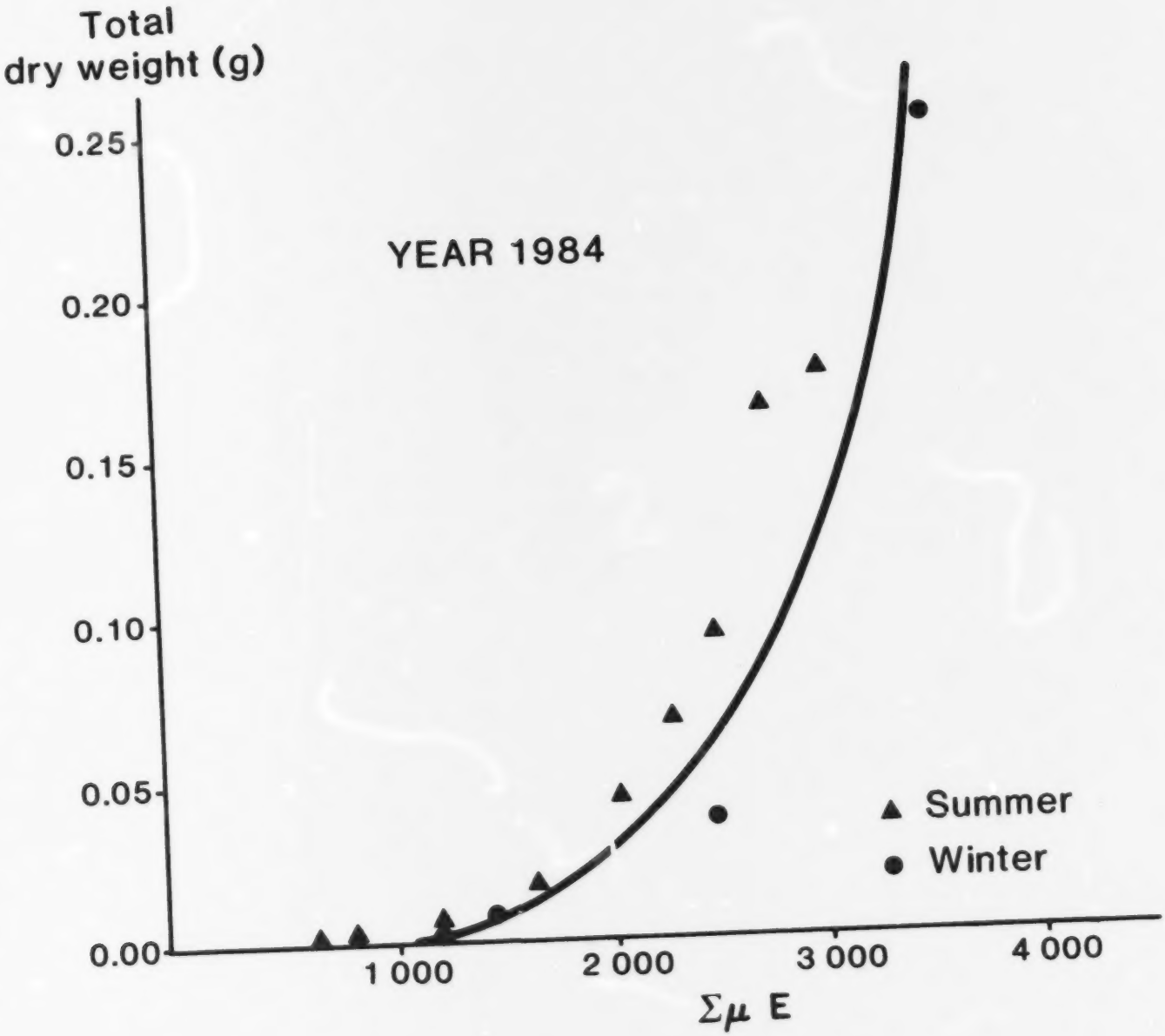

Figure 11. Accumulation of dry weight in black spruce seedlings, as a function of cumulative radiant energy. Each point represents the average of at least 16 and as many as 50 samples at 5, 10, and 15 weeks.

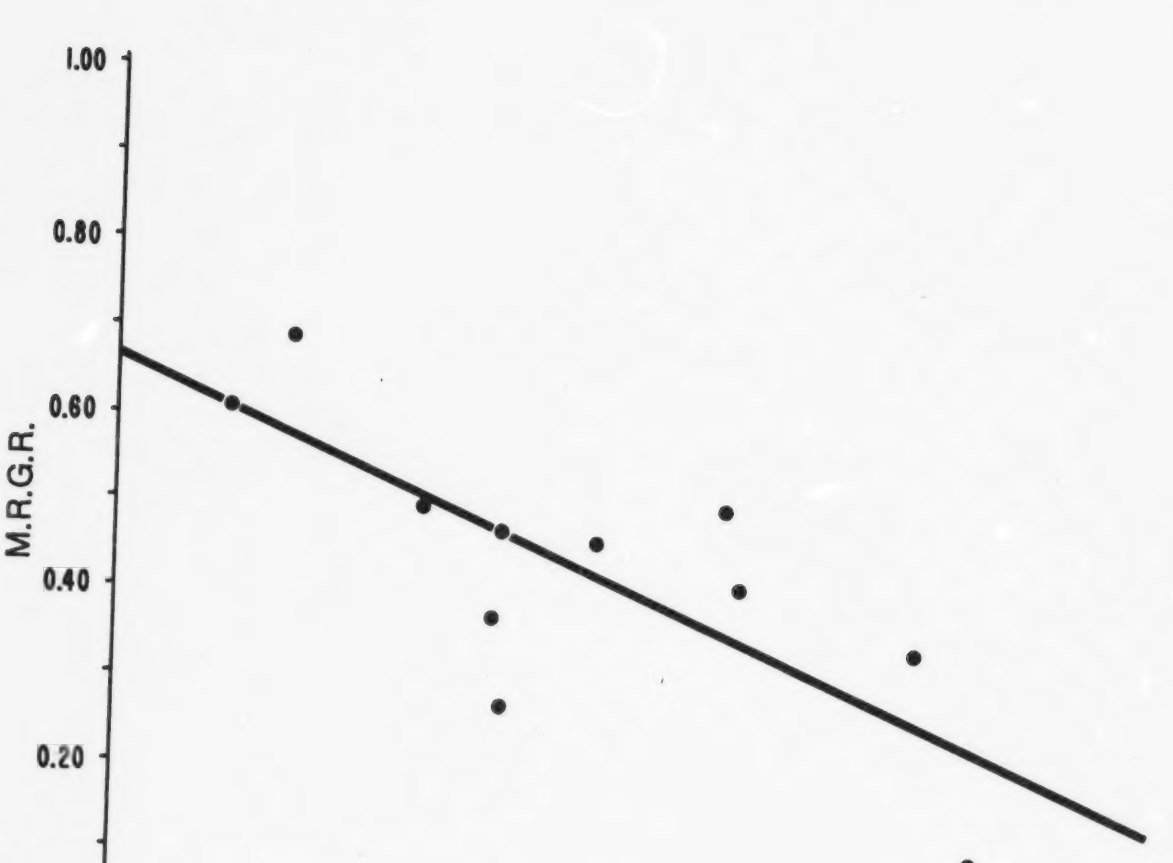

Figure 12. Mean relative growth rate as a fonction of weekly mean photon flux (spring 1984). Coefficient determination: $R^2 = 0.57$ with df = 9.

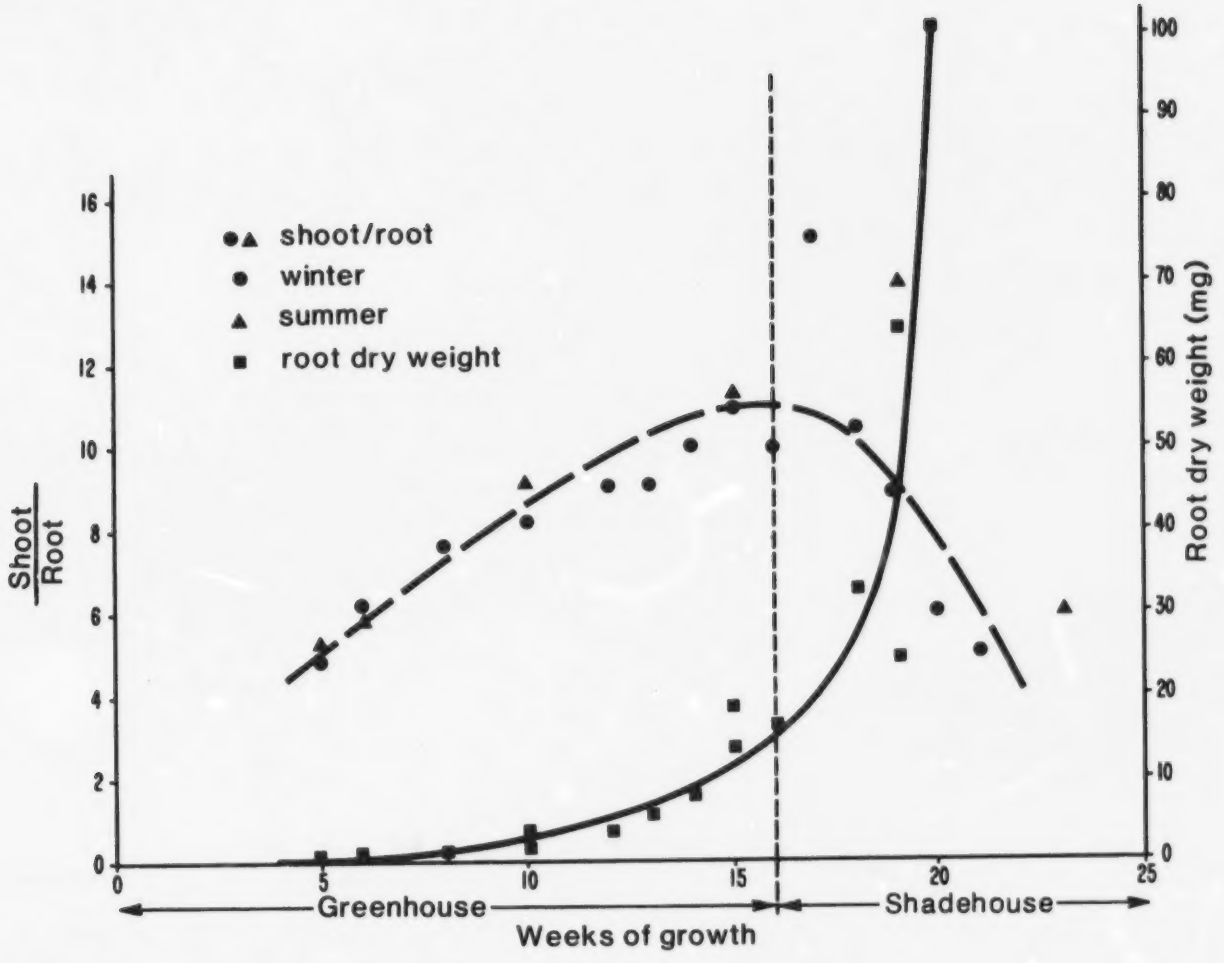

Figure 13. Morphological changes in black spruce seedlings during a growing period (1984).

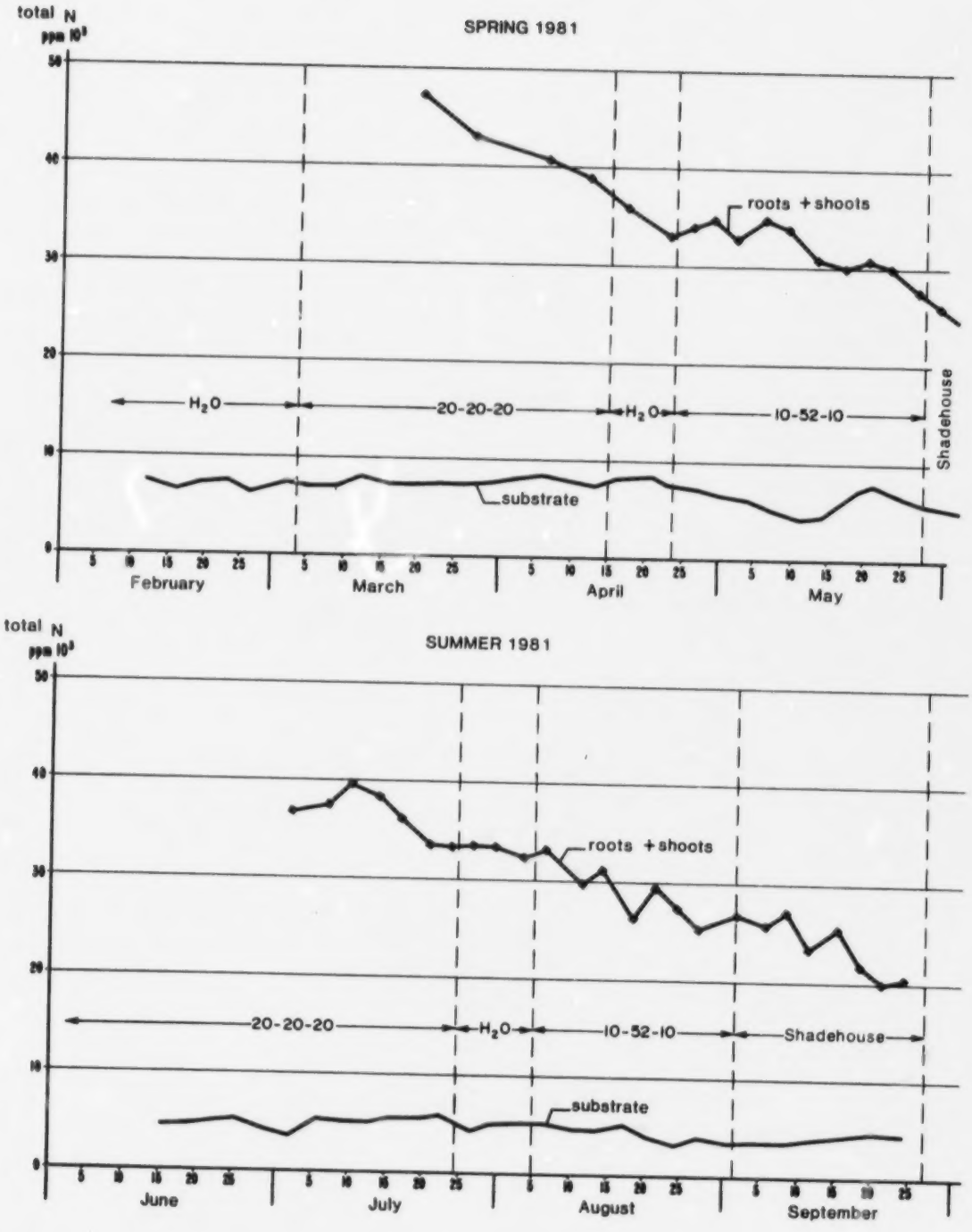

Figure 14a. N content of the shoots, roots and substrate during the 1981 production periods.

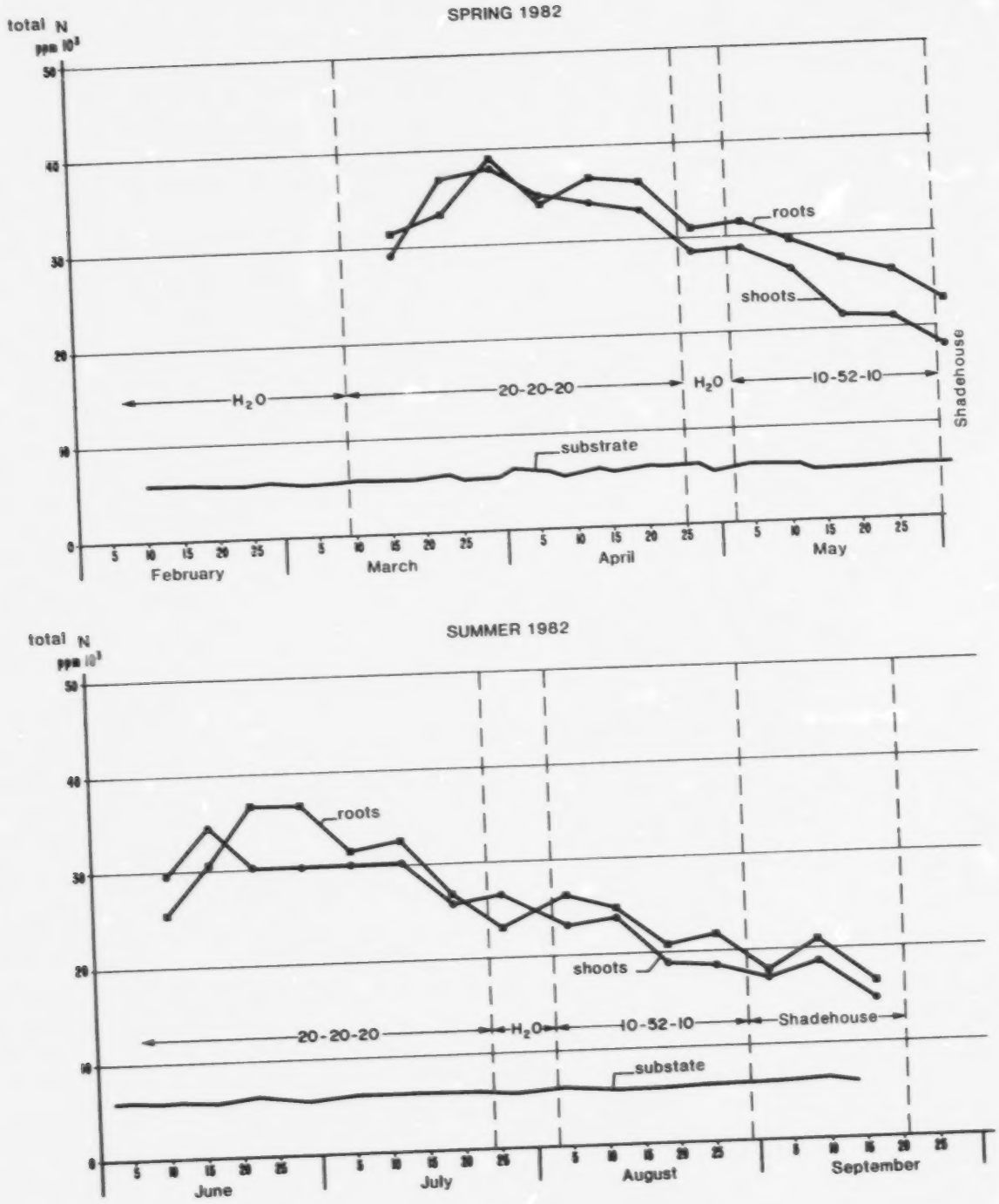

Figure 14b. N content of the shoots, roots, and substrate during the 1982 production periods.

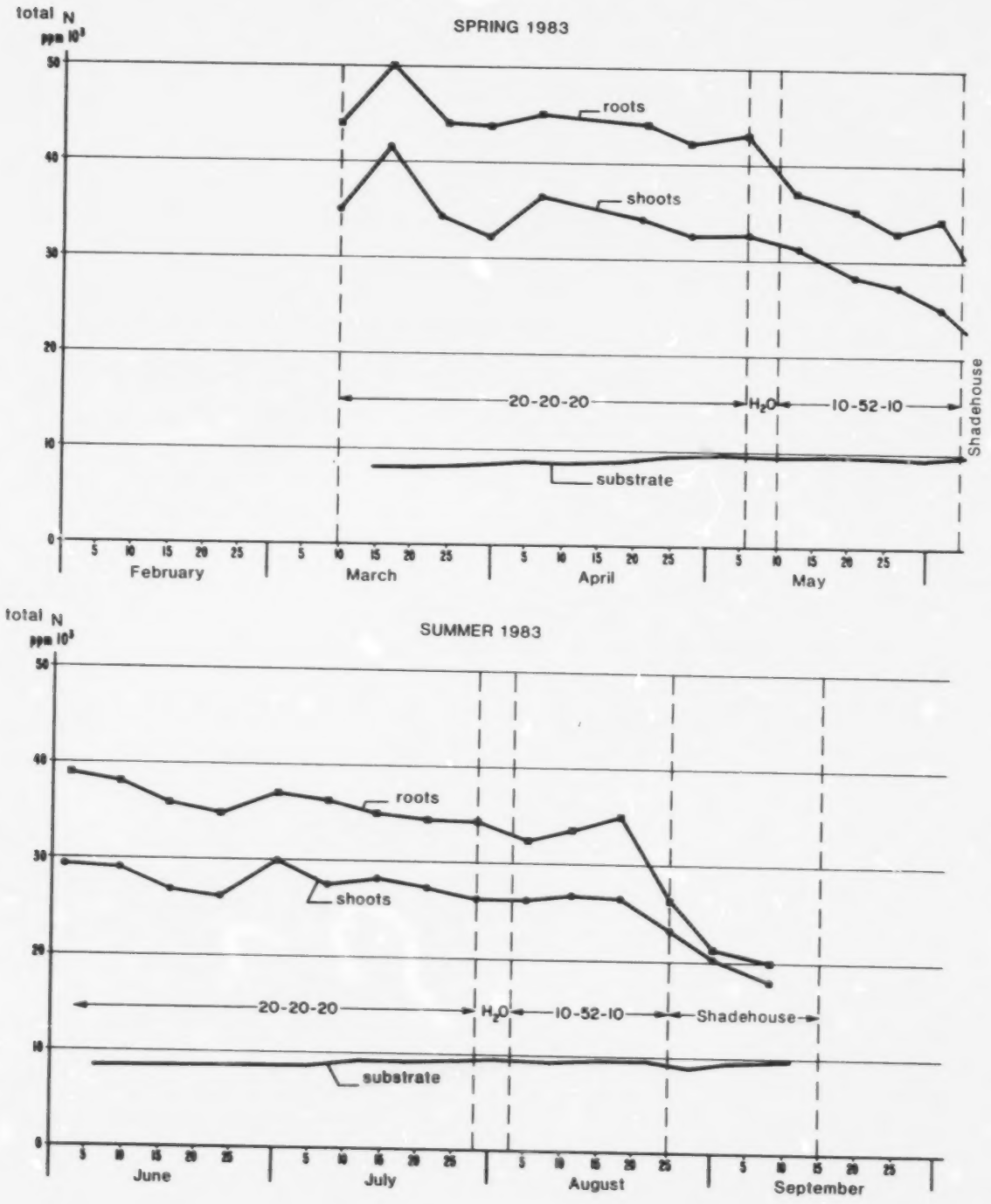

Figure 14c. N content of the shoots, roots, and substrate during the 1983 production periods.

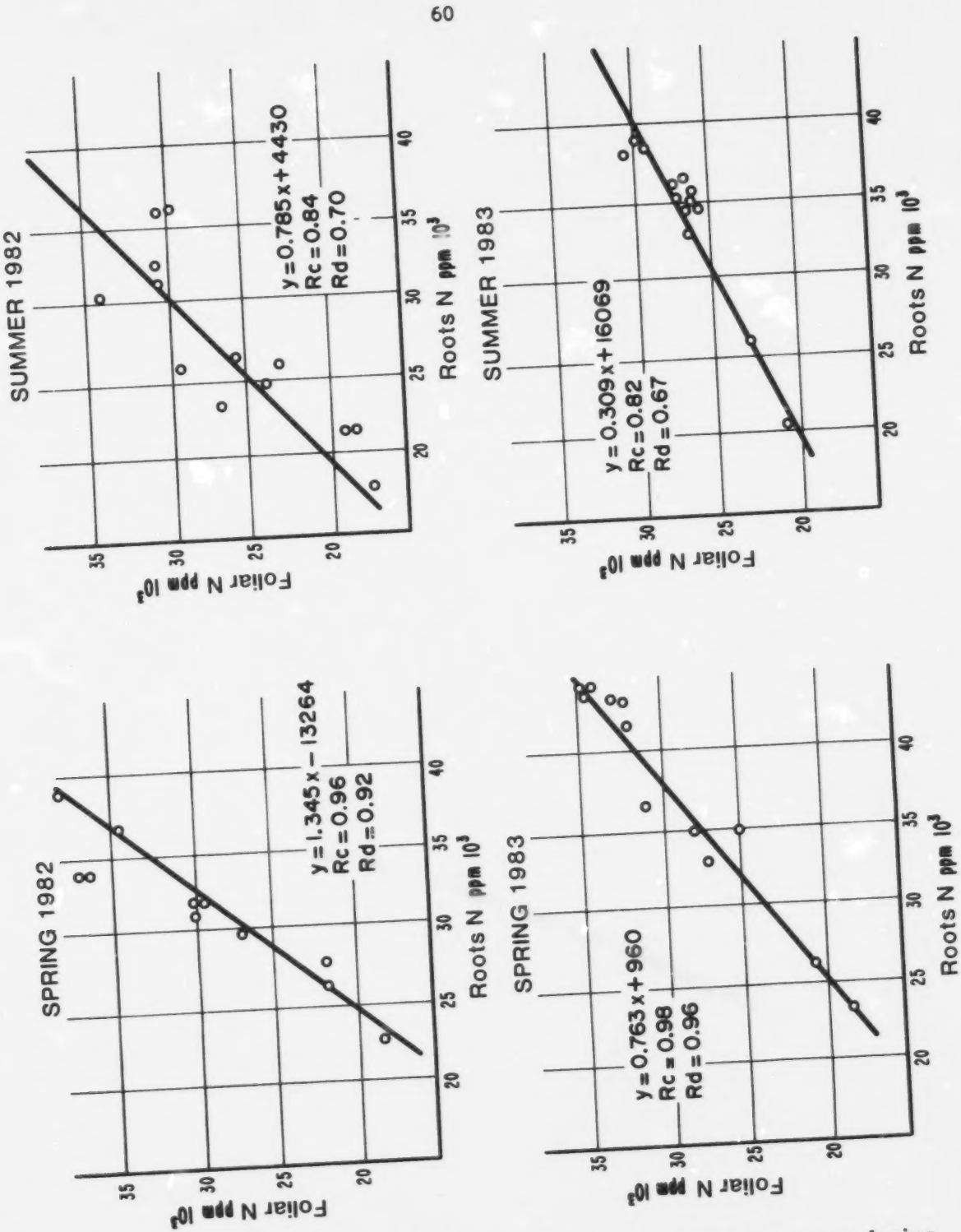

Figure 14d. Correlation between the nitrogen level the shoots and roots during the 1982 and 1983 production periods.

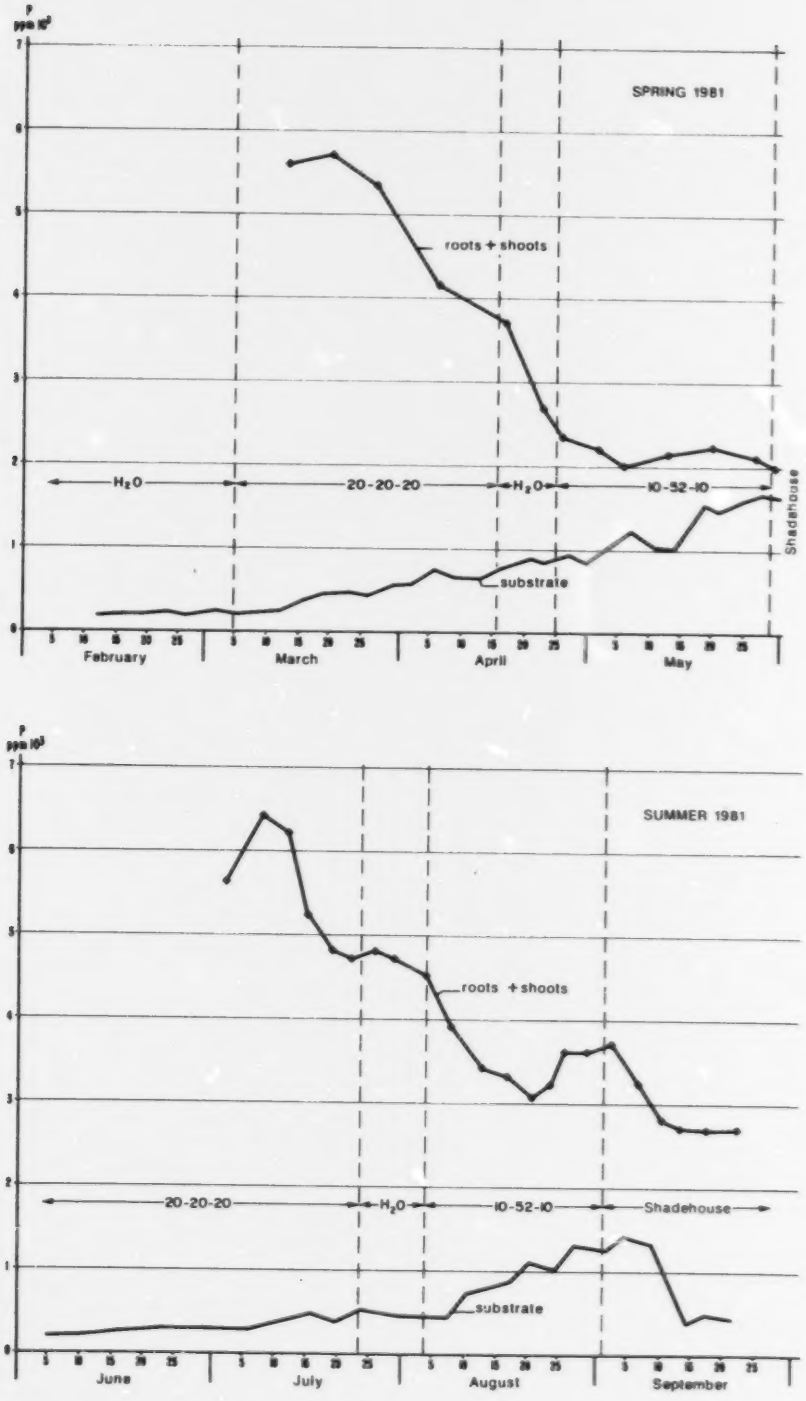

Figure 15a. P content of the shoots, roots and substrate during the 1981 production periods.

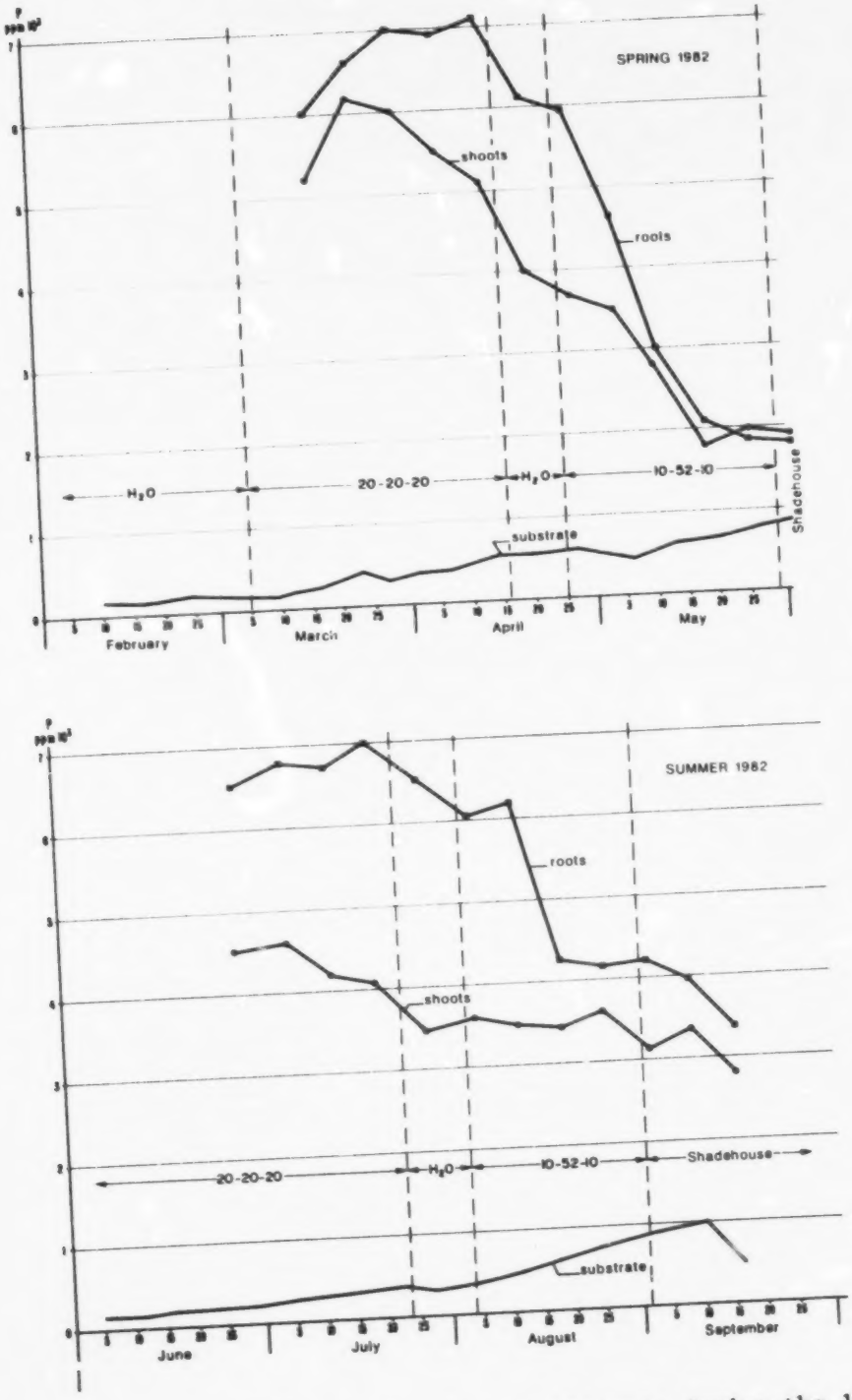

Figure 15b. P content of the shoots, roots, and substrate during the 1982 production periods.

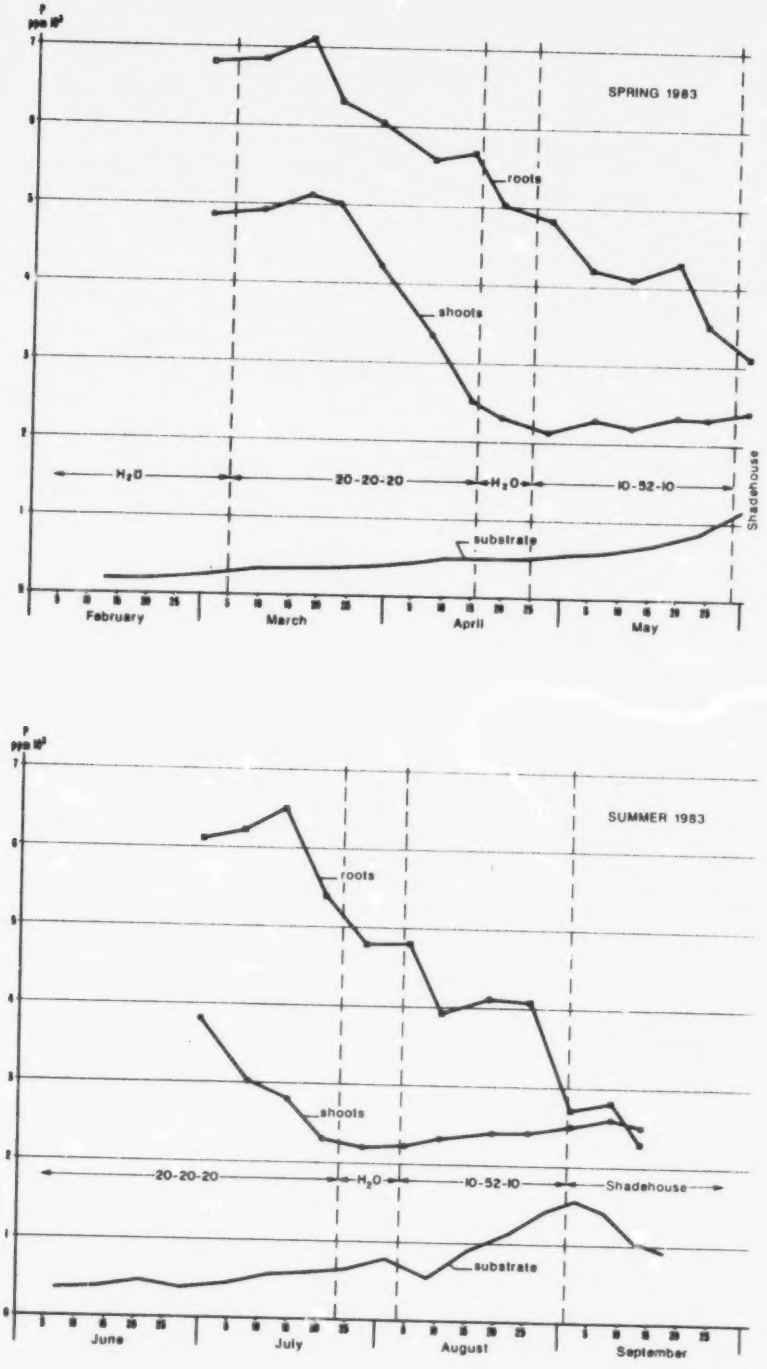

Figure 15c. P content of the shoots, roots, and substrate during the 1983 production periods.

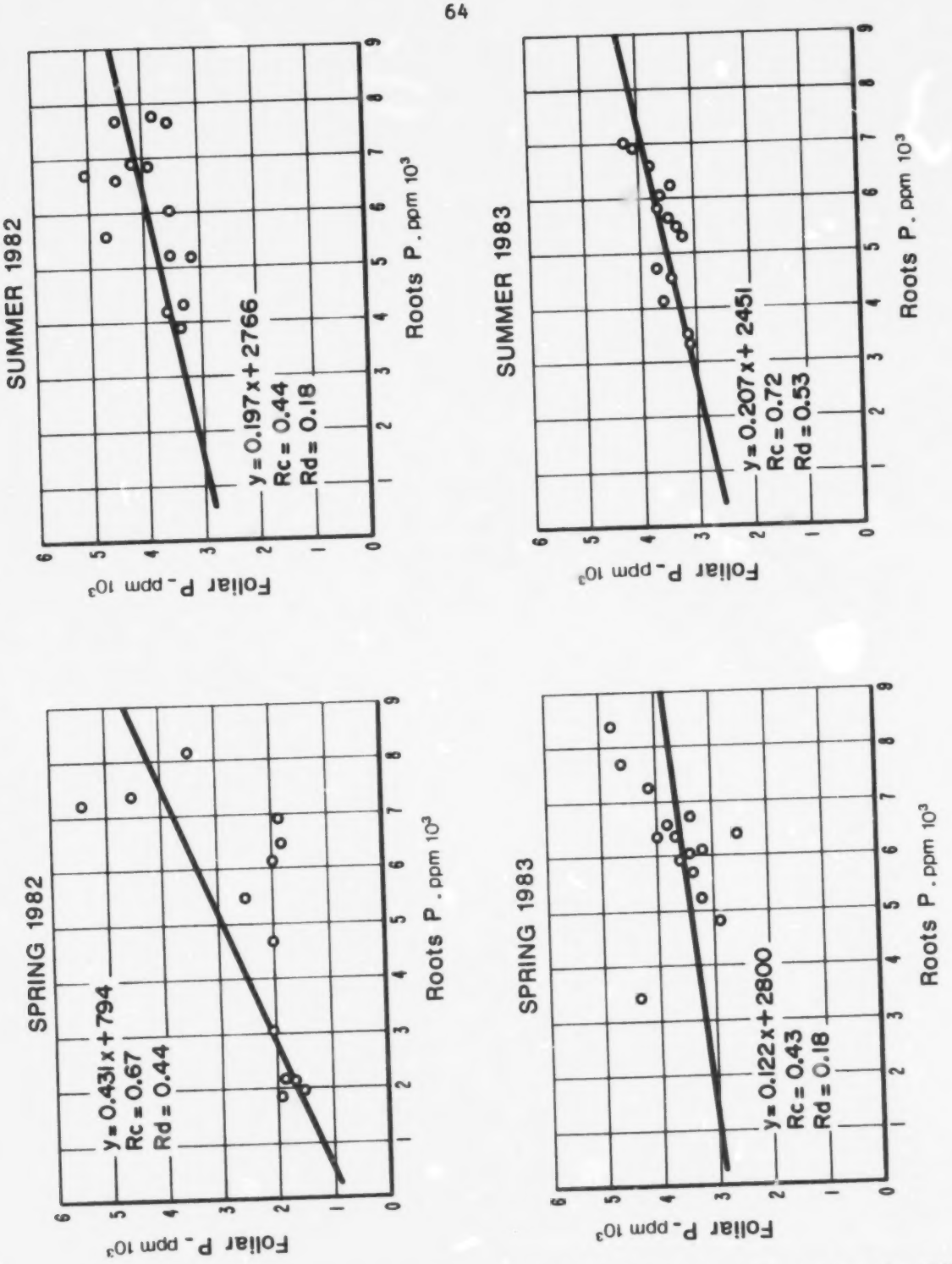

Figure 15d. Correlation between P content of the shoots and roots during the 1982 and 1983 production periods.

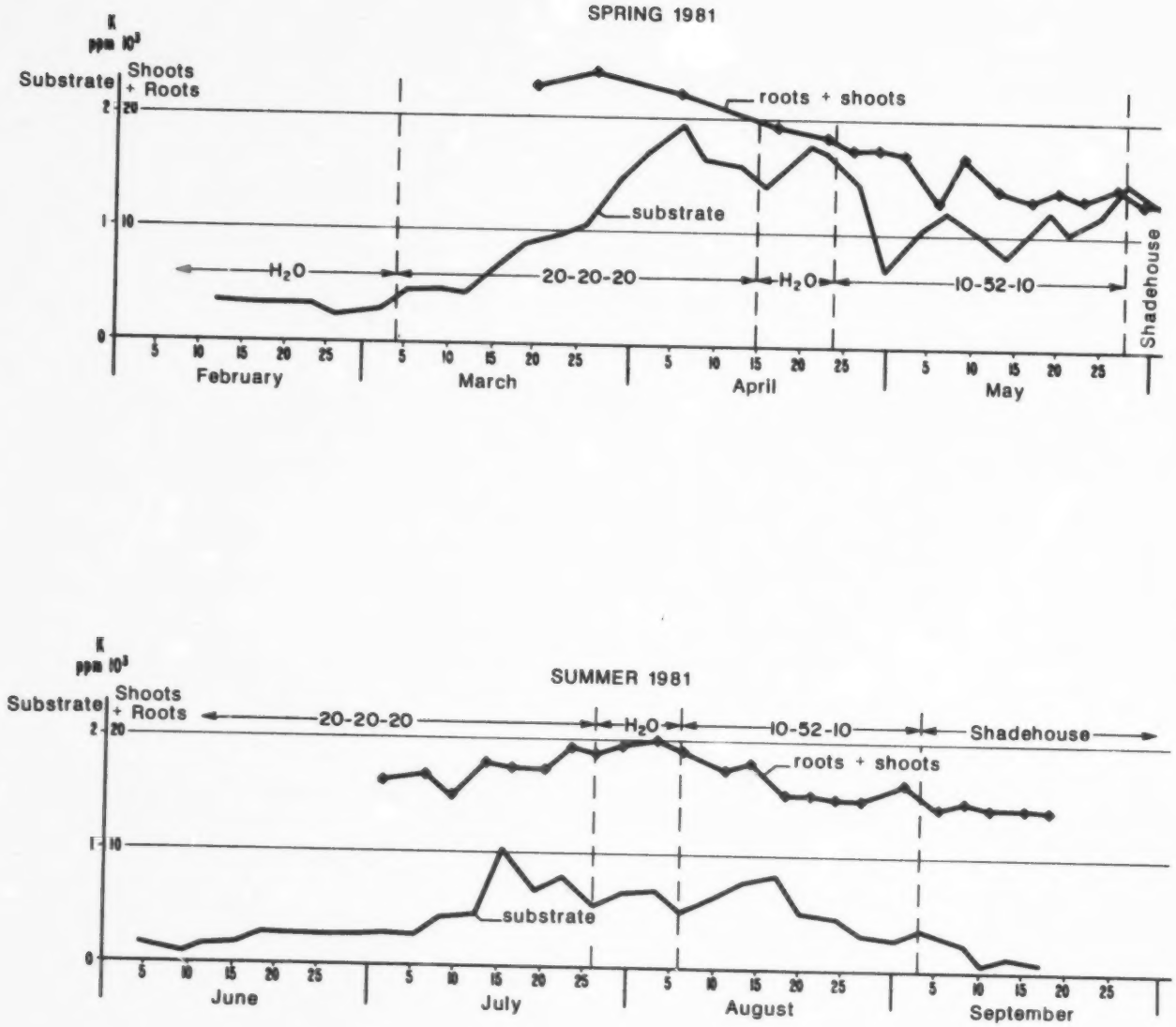

Figure 16a. Potassium content of the shoots, roots and substrate during the 1981 production periods.

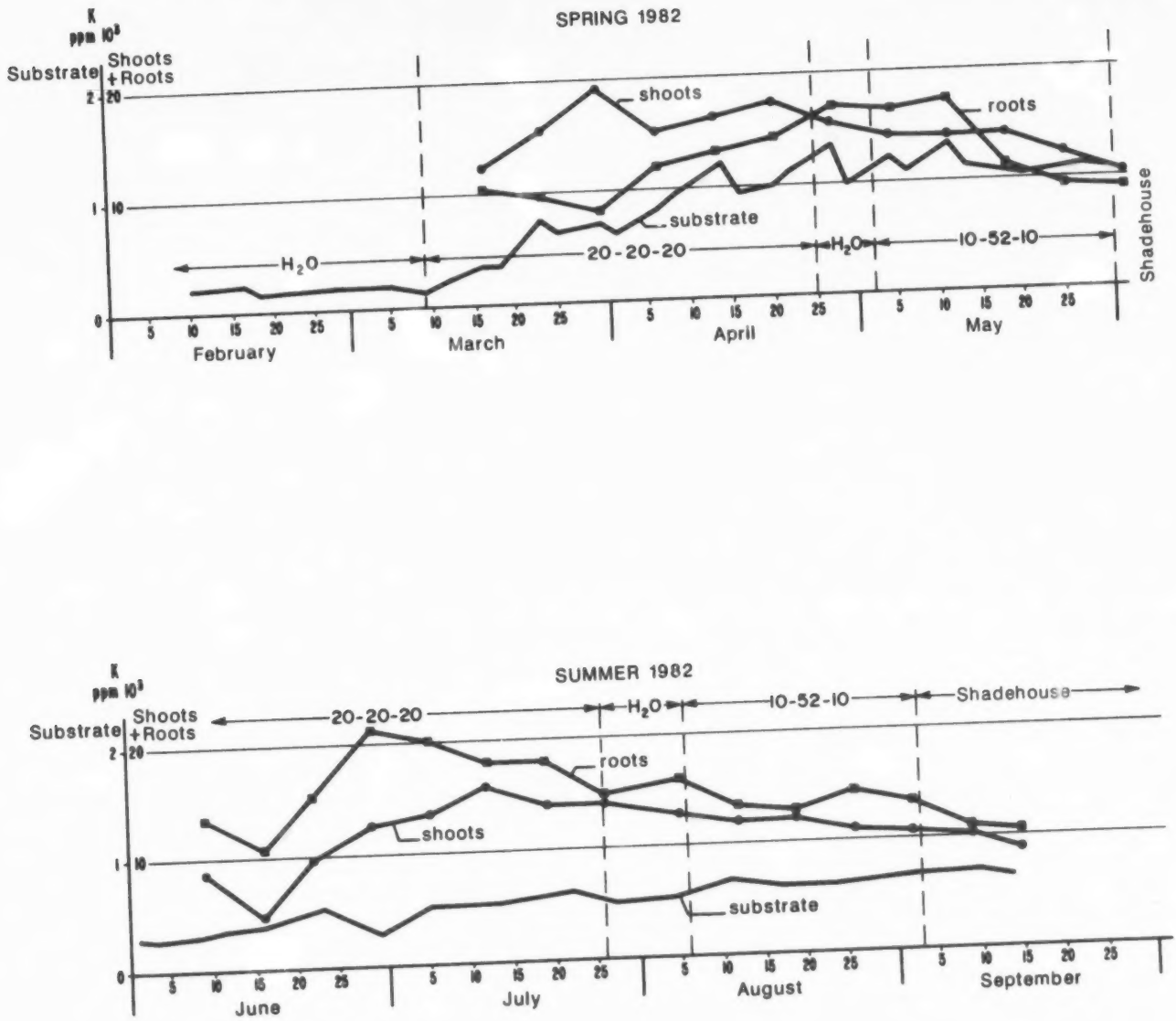

Figure 16b. Potassium content of the shoots, roots, and substrate during the 1982 production periods.

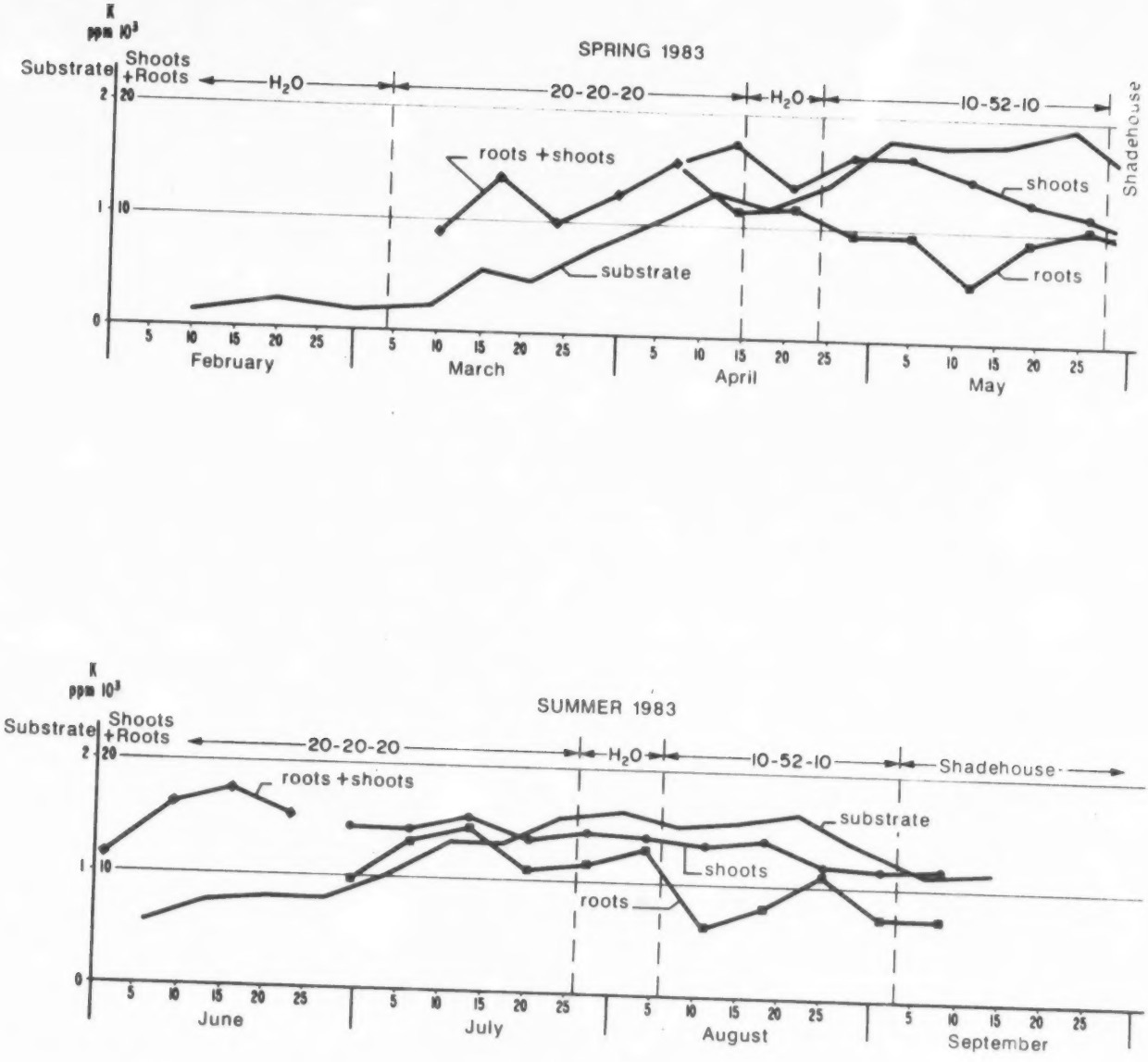

Figure 16c. Potassium content of the shoots, roots, and substrate during the 1983 production periods.

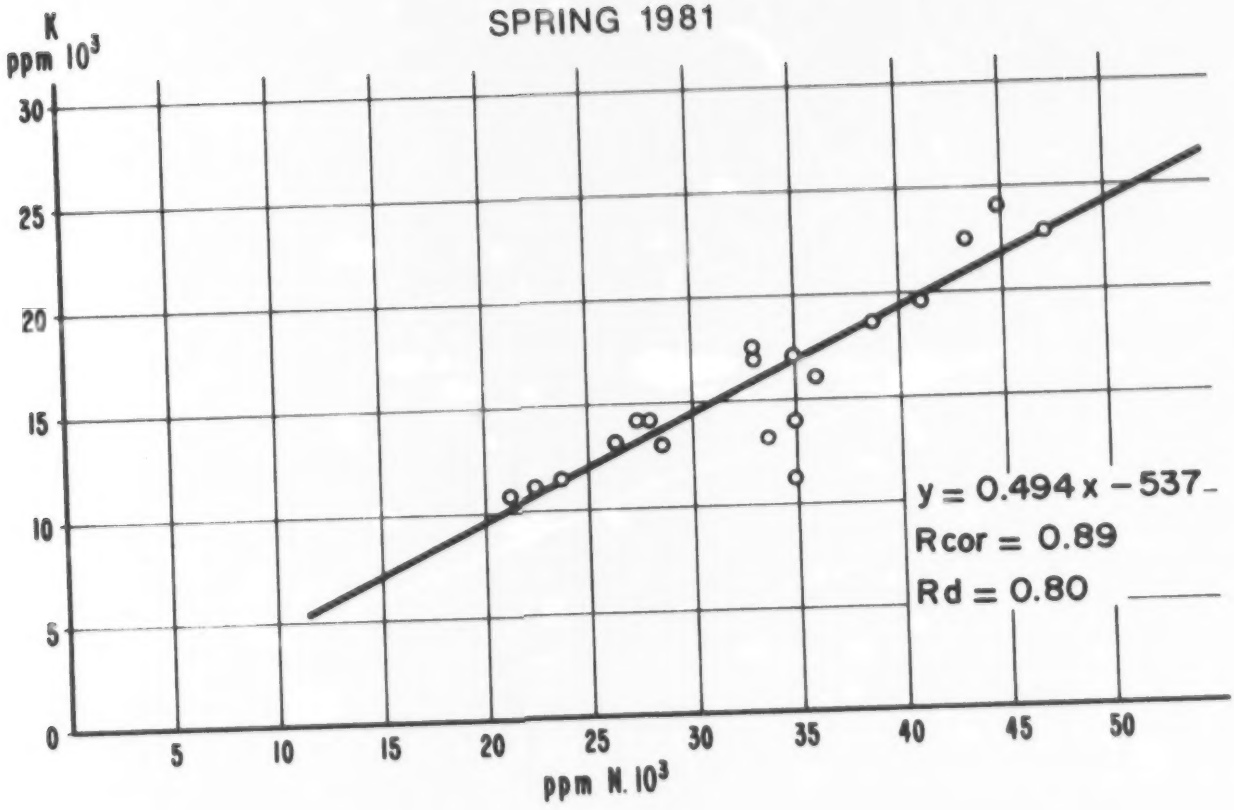

Figure 16d. Correlation between nitrogen and potassium levels in the shoots and roots (spring 1981).

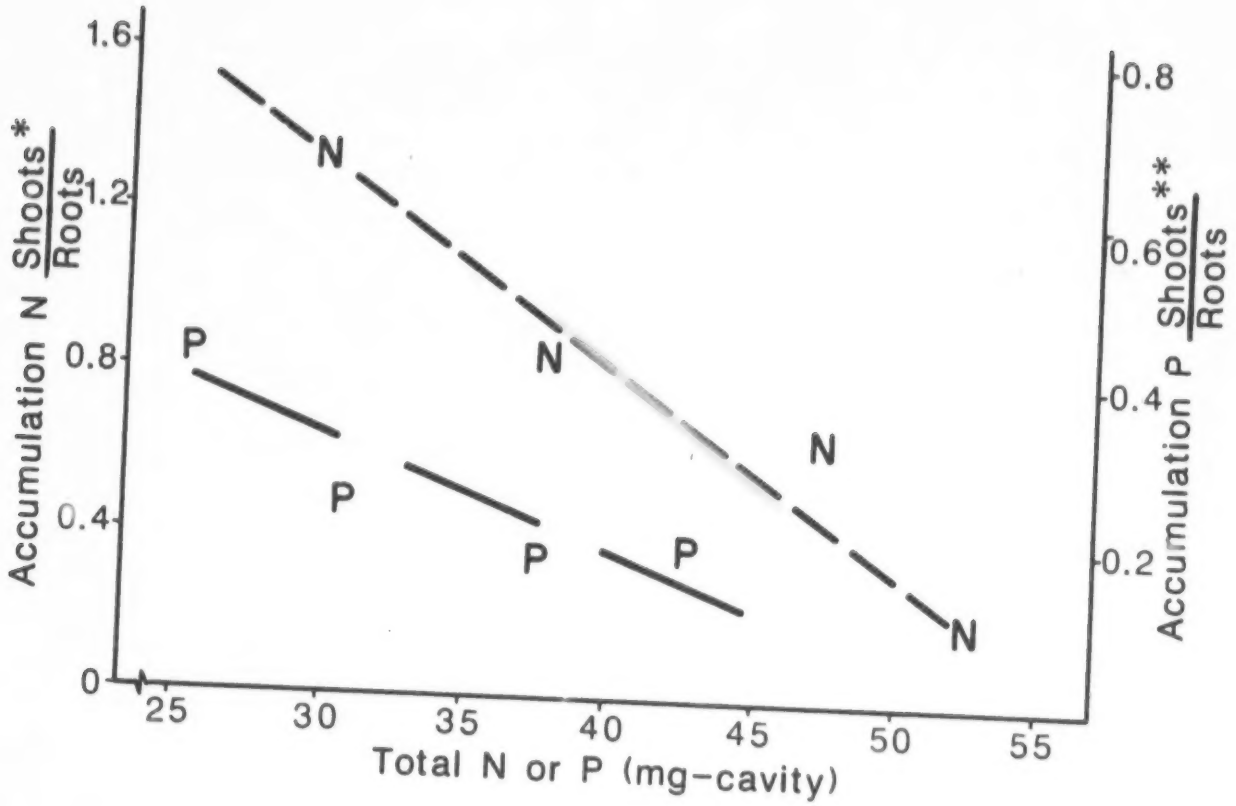

Figure 17. Effect of the concentration of elements N and P in the substrate on the accumulation of these nutrients by the seedlings.

[a] ppm N accumulation in the shoots compared with roots.

[b] ppm P accumulation in the shoots compared with roots.

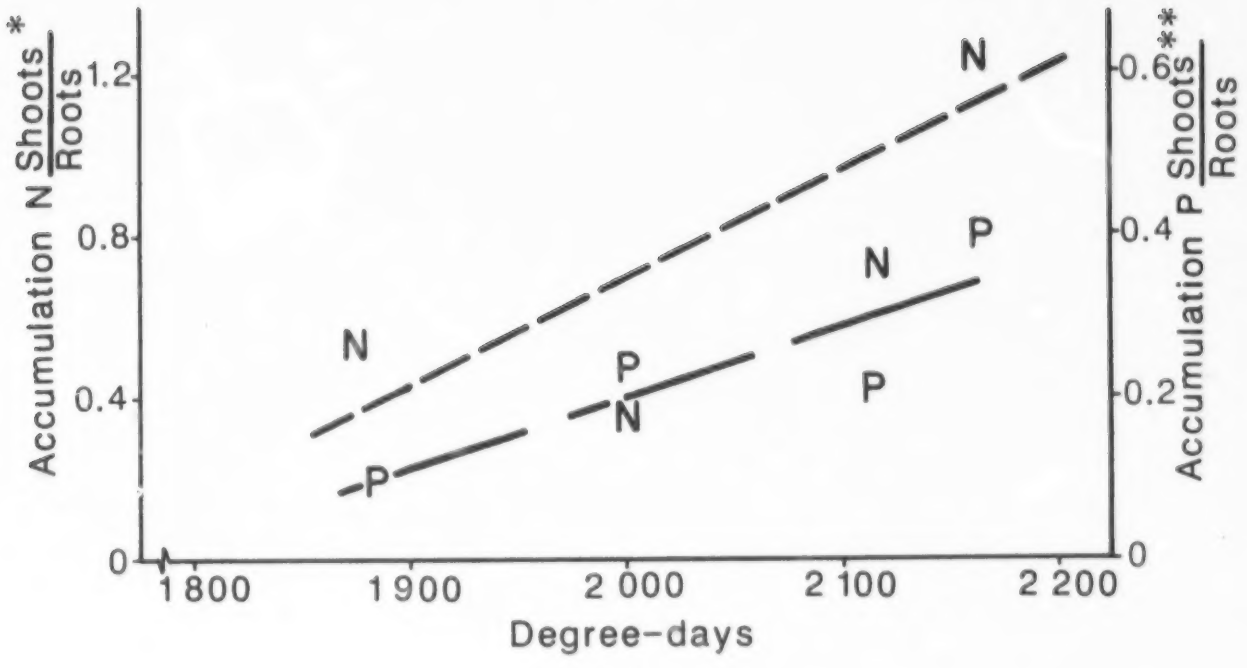

Figure 18. Effect of total degree-days during production on the accumulation of nutrients by the seedlings.

[a] ppm N accumulation in the shoots compared with roots.

[b] ppm P accumulation in the shoots compared with roots.